Refinement of Rice Water Consumptive Use During the Growing Season — Sacramento Valley

Phase II — Cal-SIMETAW Model Study

By

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Acronyms and Abbreviations

AW	applied water
Cal-SIMETAW	California Simulation of Evapotranspiration of Applied Water
CF	correction factor
CIMIS	California Irrigation Management Information System
DAU	detailed analysis unit
DWR	California Department of Water Resources
EC	eddy covariance
ETaw	evapotranspiration of applied water
ETc	crop evapotranspiration
ETo	reference evapotranspiration
G	ground heat flux
GIS	geographic information system
HS	Hargreaves-Samani
Kc	crop coefficient
km	kilometer
LE	latent heat flux density
PM	Penman-Monteith
PRISM	Parameter-elevation Regressions on Independent Slopes Model
REB	residual of the energy balance
Rn	net radiation
SIMETAW	Simulation of Evapotranspiration of Applied Water
SR	surface renewal
Tmax	maximum temperature
Tmin	minimum temperature
U_2	wind speed
UC Davis	University of California, Davis

Refining Rice Water Consumptive Use During the Growing Season – Sacramento Valley – Phase II – Cal-SIMETAW Model Study

The purpose of this study is to evaluate crop water use for the most commonly grown paddy rice variety grown in the Sacramento Valley, M206, based on field data collected from 2007 through 2009, and from 2011 through 2013. M206 was identified by the University of California (UC) Cooperative Extension Farm Advisors as the most commonly grown rice variety in the study area. Phase I of this study was conducted by the University of California, Davis (UC Davis), under contract with DWR. A brief description of both Phase I and Phase II have been included here to provide orientation as the progression of the work and linkages between each phase regarding the study results.

Phase I of the *Refinement of Rice Water Consumptive Use During the Growing Season* consists of a field study. It was prepared by Richard Snyder of UC Davis. It is based on the evapotranspiration (ET) data collected from nine paddy rice fields in the Sacramento Valley from 2011 to 2013. This study used energy balance techniques to develop a typical Kc curve.

A crop coefficient is the ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ETo). ETo is an estimate of evapotranspiration rate of a 4- to 6-inch tall, well irrigated, cool-season grass.

$$\mathrm{Kc} = \frac{\mathrm{ETc}}{\mathrm{ETo}}$$

Phase II of the *Refinement of Rice Water Consumptive Use Estimates During the Growing Season* consists of a Cal-SIMETAW model study. It was prepared by the California Department of Water Resources (DWR) and uses the newly developed Kc curve to estimate seasonal cumulative evapotranspiration of rice (CETc) for each of the California Water Plan's 19 detailed analysis units/counties within the Sacramento Valley from 1987 to 2016, based on 2014 land use data. This report presents the results of a study conducted using the daily soil-water-balance program, California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW), to estimate the water requirements of rice in the Sacramento Valley.

The results from the 1987–2016 period are based on the most updated information on crop coefficients (Kc) obtained from field research. Cal-SIMETAW was utilized to read (1) the daily weather data, (2) the crop coefficient values, and (3) crop growth dates to estimate annual curves to compute daily reference evapotranspiration (ETo), K factors, and crop evapotranspiration (ETc) for rice on each of the 19 detailed analysis units (DAUs)/counties within the Sacramento Valley for the 30-year period. Cal-SIMETAW uses a seasonal curve of daily crop coefficients and estimates ETc on each day as the product of ETo and the corresponding crop coefficient. The seasonal total ETc was computed for each DAU/county, and the totals were averaged over the 30-year period to determine a 30-year mean seasonal total ETc. The DAU/county mean seasonal total ETc estimates and acreage planted to rice during 2014 were used to determine the long-term weighted average seasonal ETc for rice for the Sacramento Valley.

Daily ETc is commonly estimated as the product of ETo and a Kc value as: ETc = ETo x Kc. Accurate estimates of crop water use are largely dependent on the accuracy of the daily crop coefficients. Many Kc

values used today are out-of-date because of changes in crop varieties, management, and irrigation systems. For example, current rice varieties tend to be much shorter than those grown 50 to 60 years ago. In addition, the equation to estimate ETo based on weather parameters has been modified and improved since many of the crop coefficient values were developed.

In this project, the University of California, Davis (UC Davis) and the California Department of Water Resources (DWR) conducted a research study to develop and refine ETc and Kc information for improving the water use information for rice (Snyder 2014). Three years of field experiments using the residual of the energy balance (REB) method, where sensible heat flux was determined by (1) eddy covariance (EC) and (2) surface renewal (SR), were conducted in three locations with different climates within the Sacramento Valley from 2011 through 2013. The main goal of the project was to determine crop coefficients for rice. The method was chosen because the accuracy is similar to other methods and the equipment is simple, easy to move, and considerably less costly than Bowen ratio, full eddy covariance, or lysimeters. In this research, in the REB method, net radiation (Rn), ground heat flux (G), and sensible heat flux (H) were measured using either the EC or the SR method. Measuring sensible heat flux with a sonic anemometer was described in Shaw and Snyder (2003). When available, the H from EC is used for the REB calculations. H from SR is used if the EC data are unavailable for some reason.

The main objective of this project was to refine and improve ETc and Kc information for rice within the Sacramento Valley using the energy balance method, with sensible heat flux from the modified surface renewal method and sonic anemometers, on three fields during a three-year period. In this study, the Kc values and the percentages of the season to identifiable growth dates B, C, and D were changed to Kc factors and dates for rice to estimate daily ET data for rice. The season is separated into initial (date A-B), rapid (date B-C), midseason (date C-D), and late season (date D-E) growth periods. Kc values are denoted KcA, KcB, KcC, KcD, and KcE, at the ends of the A, B, C, D, and E growth dates, respectively. The Kc curve for rice is based on measurements from field experiments in three paddy rice fields per year during the 2011–2013 growing seasons in the Sacramento Valley. Results indicated, that during initial growth, Kc values remained constant when the field was flooded, meaning KcA = KcB =1.1. During the rapid growth period, when the canopy increases, the Kc value decreases linearly from KcB =1.1, to KcC = 1.0. The Kc values are typically a constant value during midseason, meaning KcC = KcD. During late season, the Kc values decrease linearly from KcD = 1.0, to KcE = 0.6 at the end of the season.

The energy used to vaporize water from the surface is equivalent to the latent heat flux density (LE), which is estimated as: LE = Rn – G – H. After determining the latent heat flux density from the rice, the crop water loss, or ETc, in mm d^{-1} is calculated by dividing the LE in megajoules per meter squared per day (MJ $m^{-2}d^{-1}$) by L=2.45 MJ kg^{-1}. The result is the evapotranspiration in kg $m^{-2}d^{-1}$, which is equal to mm d^{-1} of ETc. The symbol ETc is used to represent the evapotranspiration from a surface that is evaporating at its maximum rate. Because paddy rice evapotranspiration rates are not limited by water stress, ETc is the appropriate symbol for rice evapotranspiration. The seasonal total ETc is an estimate of the volume of water that is needed to produce a crop.

Summary and Conclusions

DWR's programs require accurate estimates of consumptive use, or ETc, which is an important component in a variety of water budget analyses. The increased emphasis on water conservation, and a four-year California drought from 2012 to 2016, further underscore the need for accurate ETc. Because of

its crucial importance, a network of modified surface renewal stations (evapotranspiration measurement stations) was established in California through a joint effort between UC Davis and DWR. The network continuously updates crop coefficients to provide water resources policymakers, planners, water suppliers, and growers with improved evapotranspiration estimates.

In this project, UC Davis and DWR conducted a study to develop and refine Kc information for improving the water use information for rice in the Sacramento Valley. Three years of field experiments using the REB method, where sensible heat flux was determined by (1) EC and (2) SR, were conducted in three locations in the valley from 2011 to 2013.

As a part of the project, the Cal-SIMETAW model was utilized to use weighted-mean climate data from Parameter-elevation Regressions on Independent Slopes Model (PRISM) and Spatial California Irrigation Management Information System (CIMIS) by DAU/county over the valley from 1987 to 2016, to compute consumptive use for rice using the latest growth and Kc information to provide the best possible estimates of water use for rice. The weighted average seasonal rice ETc for the 30-year period was 34.35 inches in the Sacramento Valley. DAU 172/Sacramento County had the highest (36.34 inches) seasonal ETc, and DAU 163/Glenn County had the lowest (32.90 inches) seasonal ETc. The difference was approximately 9 percent. The 172/Sacramento County total ETc was about 5 percent more than the regional average ETc. The 163/Glenn County total ETc was approximately 4 percent less than, the regional average ETc. The weighted average seasonal estimates of ETc during dry years for the Sacramento Valley was 34.92 inches, which was about 2 percent higher than the regional estimates of ETc average during the 1987–2016 period. The increase is likely because of high ETo values, which is caused by drier air over the land surface. It is known that ETo is often greater during dry periods than normal and/or wet periods because of the effects of relative humidity. This study's estimates of ETc for the 30-year average period in the region compared quite well with the ETc value developed by Snyder. For example, the weighted average ETc estimates in the region were 34.35 inches and 34.00 inches for Cal-SIMETAW and the average of Snyder's measurements respectively, a difference in values of less than1 percent. The level of accuracy of the approach in this study for estimating ETc is highly dependent on the accuracy and limitations of input data requirements.

Project Overview

As a part of this project, the Cal-SIMETAW model was utilized to estimate the ETc of rice for combinations of DAU/counties within the Sacramento Valley from 1987 to 2016. The water balance model is a new tool developed by DWR and UC Davis to perform daily soil-water balance and determine ETc, evapotranspiration of applied water (ETaw), and applied water (AW) for use in California Water Plan Update 2018 (Orang et al. 2013). Cal-SIMETAW was operated to (1) employ weighted-mean climate data by DAU/county, and (2) compute consumptive use for rice using the growth and Kc information to provide more accurate estimates of water use for rice within the region.

Cal-SIMETAW employed weighted-mean ETo estimates from 1987 to 2004 using the PRISM temperature data and a calibrated Hargreaves-Samani (HS) equation, because only temperature data were available prior to 2005. Spatial CIMIS provided daily ETo estimates from 2005 through 2016 to determine the weighted-mean ETc data for each DAU/county.

The Cal-SIMETAW computer application program was developed by DWR and UC Davis to help obtain accurate estimates of ETc and ETaw for agricultural crops, and other surfaces, which account for most evapotranspiration losses. The computer application also helps with estimates of water contributions from irrigation, precipitation, and ground water seepage. As previously indicated, the model computes crop evapotranspiration as the product of ETo and a crop coefficient value (ETc = ETo x Kc). The model also computes ETaw as the seasonal evapotranspiration minus water supplied by stored soil moisture, effective rainfall, and seepage from canals. The accuracy of estimates obtained from this model mainly depends on the accuracy and limitations of the input data. Improvements to this model are possible if the crop coefficients are updated to better match the current conditions.

This report is organized to:

- Provide a brief description of the Cal-SIMETAW model and its database.
- Show a comparison between Cal-SIMETAW estimates of ETo, and ETo computed based on data from CIMIS.
- Compare the spatially distributed Cal-SIMETAW PRISM-ETo datasets with spatial CIMIS, which was developed by DWR and UC Davis to use point-based CIMIS measurements and remote sensing to provide a statewide grid of ETo information.
- Show comparisons of daily and monthly weighted-mean ETo estimates from the PRISM and Spatial CIMIS models over irrigated land by DAU/county over the Sacramento Valley.
- Focus seasonal crop evapotranspiration estimates for rice based on Cal-SIMETAW using the crop coefficients within the Sacramento Valley.
- Show comparison of seasonal rice ET and the 30-year average (1985–2014) by DAU/county.

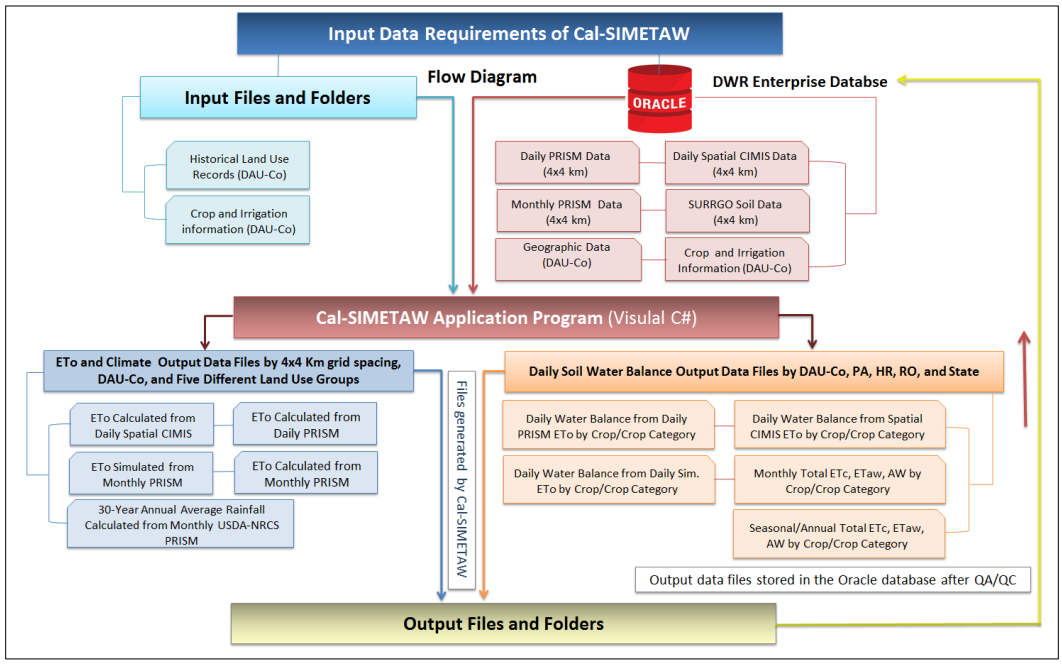
Model Description

Cal-SIMETAW was written using Microsoft C# for calculations, and Oracle Spatial 11 g for data storage, to provide a new tool for obtaining accurate estimates of ETc, ETaw, and AW for 132 individual crops, 20 crop categories, and four land-use categories by DAU/county. Cal-SIMETAW provides spatial soil and climate information, and it uses historical crop and land-use category information with precipitation and ETc data to generate hypothetical water balance irrigation schedules to determine ETaw by DAU/county over California for the period of records. The application uses the daily climate data, (maximum temperature [Tmax], minimum temperature [Tmin], and precipitation), which were derived from monthly U.S. Department of Agriculture-Natural Resources Conservation Service PRISM data (Parameter-elevation Regressions on Independents Slopes Model Group 2011) and daily National Climatic Data Center climate station data to cover California on a 4 kilometer (km) x4 km grid spacing. From the PRISM data, ETo is estimated using the HS equation that was calibrated to estimate regional Penman-Monteith (PM) equation ETo, to account for spatial climate differences. In addition to using historical data, Cal-SIMETAW employs near real-time ETo information from Spatial CIMIS, which is a model that combines CIMIS weather station data and remote sensing to provide a statewide grid of ETo information. A second database containing the available soil water-holding capacity and soil-depth information for all of California was developed from the U.S. Department of Agriculture-Natural Resources Conservation Service Soil Survey Geographic database.

Cal-SIMETAW uses batch processing to read (1) the climate data, (2) the surface/crop coefficient values, (3) growth dates to estimate annual curves, (4) soil information, (5) crop and irrigation information, and

(6) surface area of each crop and land-use category on each of the 482 DAU/counties. And then, the program computes daily ETo, Kc factors, ETc, daily water balance, effective rainfall, ETaw, and other categories, for every surface within each of the 482 DAU/counties during the period of record. Figure 1 illustrates the structure, database, and lists of input and output data files of the Cal-SIMETAW model.

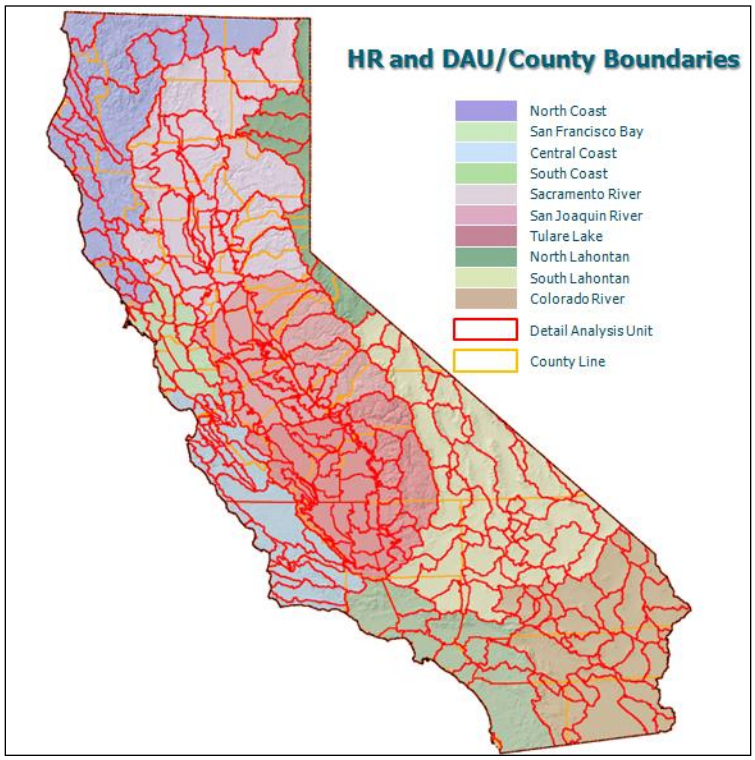
Figure 1. Structure, Database, and Lists of Input and Output Data Files of the Cal-SIMETAW Model



Detailed Analysis Units/County

DWR has subdivided California into 482 DAU/counties, which are geographic areas having relatively uniform ETo throughout each DAU. The DAUs are used for estimating water demand by agricultural crops, and other surfaces, for water resources planning. DAUs are based on watershed and other factors related to water use and movement within a region, all of which are often split by geopolitical boundaries of different counties. DAU/counties are the smallest study areas used by DWR. The largest study areas are California's 10 hydrologic regions. Land-use surveys are periodically completed within each DAU/county by DWR staff, and the acreage for each crop grown within a multiple crop/land-use category is recorded for most DAU/counties. Using percentages of each crop within a DAU/county, the individual crop coefficients and growth rates are analyzed to determine a weighted-mean Kc curve for each category. Each DAU/county can have as many as 20 crops and four land-use categories with weighted-mean Kc curves (Figure 2).

Figure 2. Study Area's Hydrologic Regions (HRs), Detailed Analysis Units (DAUs), and Counties



Reference Evapotranspiration Equations Used in Cal-SIMETAW

The America Society of Civil Engineers (ASCE) and the Food and Agriculture Organization of the United Nations (FAO) have recommended the daily standardized ETo equation for short canopies to estimate ETo and to evaluate the potential accuracy of other methods (American Society of Civil Engineers-Environmental and Water Resources Institute 2005, Allen et al. 1998). The daily ETo equation is a modified form of the PM equation using a fixed canopy resistance r_c=70 s m^{-1} and an aerodynamic resistance r_a=208/U_2, where U_2 is the wind speed measured at 2 meters above a grass field.

A major obstacle preventing the widespread use of the PM equation is the lack of sufficient climate data. When only temperature data are available, a simple, empirical HS equation is often used to compute ETo. But, this equation may underestimate ETo at sites influenced by windy, arid conditions, and overestimate ETo at locations with calm winds and humid conditions. Consequently, the equation may require local calibration before use at some sites.

The daily (24-hour) PM equation is:

$$\mathrm{ETo} = \frac{0.408\,\Delta\,(Rn - G) + \Upsilon\,\frac{900}{T + 273}\,u_2\,(e_s - e_a)}{\Delta + \Upsilon(1 + 0.34\,u_2)} \qquad (1)$$

where ETo is the reference evapotranspiration (mm d^{-1}), Δ is the slope of the saturation vapor pressure curve (kilopascal [kPa $^oC^{-1}$]) at the daily mean air temperature (^oC), Rn and G are the net radiation and

soil heat flux density in MJ $m^{-2}d^{-1}$, γ is the psychrometric constant (kPa $^oC^{-1}$), T is the daily mean temperature, u_2 is the mean wind speed in m s^{-1}, e_s is the saturation vapor pressure (kPa) calculated from the mean air temperature for the day, and e_a is the actual vapor pressure (kPa) calculated from the mean dew point temperature for the day. The coefficient 0.408 converts $R_n - G$ from MJ $m^{-2}d^{-1}$ to mm d^{-1}, and the coefficient 900 combines several constants and converts units of the aerodynamic component to mm d^{-1}. The product 0.34 u_2 in the denominator is assumed ratio surface resistance (r_c = 70 s m^{-1}) to the aerodynamic resistance (r_a =208/u_2 s m^{-1}) for a 0.12-meter-tall canopy. It is assumed that the temperature, humidity, and wind speed are measured between 1.5 meters (5 feet) and 2.0 meters (6.6 feet) above a grass-covered soil surface.

In addition to the PM equation for ETo, the calibrated HS equation is used to compute ETo using daily PRISM weather data when complete weather data sets are unavailable. The HS equation requires only the latitude of the site of interest and the minimum and maximum daily air temperatures. The HS equation for ETo is:

$$ETo = 0.0023 (Tc + 17.8) Ra (Tr^{0.5}) \quad (2)$$

where Tc is the monthly mean temperature at the site, Ra is the extraterrestrial solar radiation (MJ m^{-2} d^{-1}), and Tr is the difference between the maximum and minimum temperatures for the month. When weather data from Spatial CIMIS were available, the PM equation was used in this study to provide ETo, otherwise, a calibrated HS equation was used.

Reference Evapotranspiration Estimates Using the Historical PRISM Temperature Data

Because only temperature data were available prior to 2005, it was decided to use daily maximum and minimum air temperature, and the HS (1982, 1985) equation, to calculate an approximation for ETo. Using recent climate data from CIMIS, comparisons were made between HS ETo and CIMIS ETo. Discrepancies were noted depending on regional climate differences. In general, HS ETo was lower than CIMIS ETo under windy conditions, and it was higher than CIMIS ETo under calm conditions. Using approximately 130 CIMIS weather stations distributed across the state, a 4 km x 4 km grid of correction factors for the HS ETo equation was developed. There are many daily temperature and precipitation weather stations in California, but the PRISM data set, which was developed by Oregon State University (Parameter-elevation Regressions on Independents Slopes Model Group 2011), provided a long-term geographic information system (GIS) database of historical daily maximum and minimum temperature and precipitation on the same 4 km x 4 km grid as the correction-factor GIS map. As a result, using the PRISM historical temperature data to compute HS ETo and the calibration factors, Cal-SIMETAW is able to produce CIMIS ETo estimates on 4 km x 4 km grids across the state from October 1921 to September 2010.

Reference Evapotranspiration Correction Factors

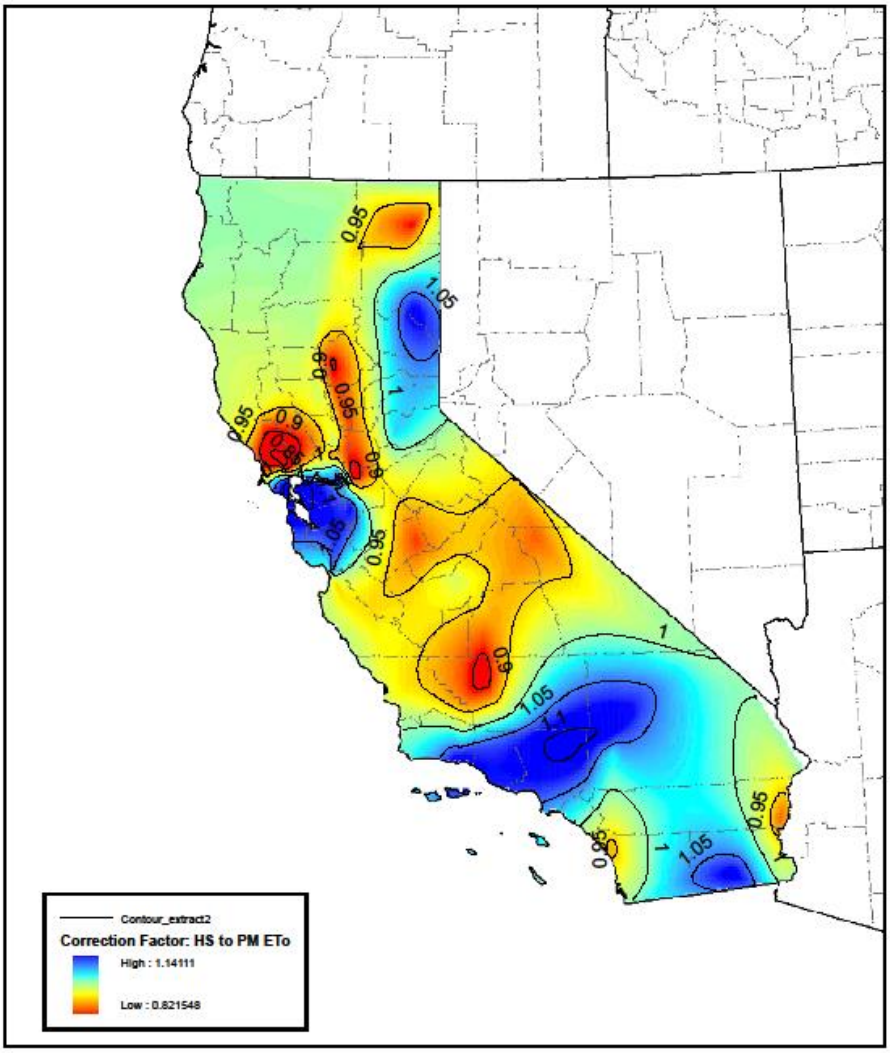
National Climatic Data Center stations were paired with neighboring CIMIS stations from the time CIMIS stations came on-line. Corresponding data for the paired stations were selected from the UC Davis Integrated Pest Management website (http://ipm.ucdavis.edu). The correction factor (CF) was calculated as:

$$CF = PM/HS \quad (3)$$

where PM and HS are ETo estimates from the daily standardized reference evapotranspiration and HS equations, respectively.

Spatial interpolation was completed using ArcGIS and a 4 km gridded raster map for CF was produced (Figure 3). The CF values fell within 15 percent of 1.0. The CF values were archived for each 4 km x 4 km grid area. The grid areas were stored in files designated by the DAU/county number.

Figure 3. Correction Factor (CF) Distribution for Converting Hargreaves-Samani (HS) ETo to Penman-Monteith (PM) ETo



Notes:
ETo = reference evapotranspiration
ETo = HS x CF

Real-Time Reference Evapotranspiration Estimates Using Spatial CIMIS

DWR and UC Davis developed a new map product called "Spatial CIMIS," which is the combination of daily CIMIS weather station and remote sensing data, to provide a grid of ETo information, using the daily PM equation. Although there are approximately 130 CIMIS weather stations in California, many locations have limited weather data for ETo estimation, so there are gaps in the spatial data. To resolve

this problem, DWR and UC Davis used satellite data to estimate solar radiation between stations, and algorithms to estimate changes in temperature, humidity, and wind speed between stations. The result is Spatial CIMIS, which provides spatial ETo estimation throughout the state. Cal-SIMETAW uses GIS to incorporate the spatial ETo estimates into the program and provide daily maps of crop ETc throughout the state.

Verification of Cal-SIMETAW Predictions of Reference Evapotranspiration

CIMIS network station measurements are among the most reliable direct datasets of daily weather variables including solar radiation, Tmax, Tmin, wind speed (U_2), and dew-point temperature. ETo, computed by the daily (24-hour) PM equation, has been recommended by both the ASCE and the FAO.

The daily ETo values estimated by Cal-SIMETAW, using daily PRISM and Spatial CIMIS weather data, were validated against CIMIS ETo estimates from October 2004 to September 2010 at Davis, Gerber, Durham, and Nicolaus in the Sacramento Valley. The CIMIS weather stations at these sites were chosen because, (1) they have high-quality weather data, (2) they contain longer weather records, and (3) they are distributed almost evenly across the Sacramento Valley. Plots of the daily ETo from October 2004 to September 2010 are given in Appendix A. The results show reasonably good agreement among CIMIS-based estimates of ETo and those calculated from the calibrated HS equation using daily PRISM weather data and daily PM equation using Spatial CIMIS weather data.

Detailed Analysis Units/County-Level Reference Evapotranspiration Correction Factors

Because only temperature data were available prior to 2005, a decision was made to use the DAU/county weighted-mean ETo estimates from 1987 to 2004 using the Tmax and Tmin from PRISM, and the Spatial CIMIS ETo data from 2005 to 2016. That was done in order to determine the weighted-mean ETc data for each of the DAU/counties within the Sacramento Valley during a 30-year period (1987–2016).

To test the accuracy of estimated weighted-mean ETo using the PRISM-temperature data, the average annual estimates of weighted-mean ETo based on the PRISM-temperature data were compared with the limited Spatial CIMIS weather data for 19 DAU/counties, on a daily basis from 2005 to 2010. Comparison between the average annual ETo estimates of the two methods from 2005 to 2010 showed close agreement between Spatial CIMIS-based estimates of ETo and those of the calibrated HS equation, in most cases. For the six DAU/counties (166-Butte, 166-Glenn, 168-Butte, 168-Sutter, 172-Sutter, and 186-Yolo) the calibrated HS ETo equation of the Cal-SIMETAW model slightly overestimated the ETo in this analysis. It ranged from 5.68 percent to 6.73 percent because it did not adequately account for the effects of spatial climate differences. Table 1 shows average annual calculated weighted-mean ETo for the six DAU/counties based on the PRISM and Spatial CIMIS climate data from 2005 to 2010.

In order to correct for the effects of spatial climate differences, and develop the appropriate DAU/county coefficients for calibrating the HS ETo equation, the first calculation was a monthly correction coefficient for each month of each year (2005–2009). The calculated correction coefficients for each month were averaged, resulting in one correction coefficient for each month. The 12 monthly ETo correction factors for each DAU/county were used to fit the ETo estimates based on the PRISM temperature data with estimates of ETo from the Spatial CIMIS model. Finally, the correlation between the PRISM and Spatial

Table 1. Average Annual Estimates of ETo from Two Different Methods by DAU/County (2005-2010)

DAU/County	Average Year	PRISM ETo (inches)	Spatial CIMIS ETo (inches)	Variation
166-Butte	2005-2010	54.18	50.68	6.46%
166-Glenn	2005-2010	54.05	50.67	6.24%
168-Butte	2005-2010	54.21	50.67	6.53%
168-Sutter	2005-2010	54.33	51.25	5.68%
172-Sutter	2005-2010	55.46	52.32	5.67%
186-Yolo	2005-2010	56.29	52.51	6.73%

Notes:
CIMIS = California Irrigation Management Information System, DAU = detailed analysis units, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes Model

CIMIS weighted-mean ETo data from 2005 to 2010 was tested, and a strong correlation was found, with results yielding a near-perfect regression coefficient. The plots of daily and monthly weighted-mean ETo estimates for PRISM and Spatial CIMIS on each of the 19 DAU/counties within the Sacramento Valley, from January 2005 to September 2010, are given in Appendix B. Additional plots of daily estimated weighted-mean ETo and cumulative ETo during a five-year period for PRISM and Spatial CIMIS are also given in Appendix B for further validation.

Verification of Reference Evapotranspiration Correction Factors

As a final verification of our regression-coefficient-based HS equation for all the DAU/counties in the Sacramento Valley, the model predictions of daily and monthly weighted-mean ETo data during a 25-year period (1981–2004) based on the PRISM temperature data were compared with those of Spatial CIMIS, averaged over the most recent five years, 2005–2010. This step was necessary because the available weighted-mean ETo data from Spatial CIMIS for the DAU/counties to develop the ETo correction factors, had already been used. The plots in Appendix C illustrate that all Cal-SIMETAW estimated ETo, based on the PRISM climate data, were well-correlated with Spatial CIMIS data.

Crop Coefficients

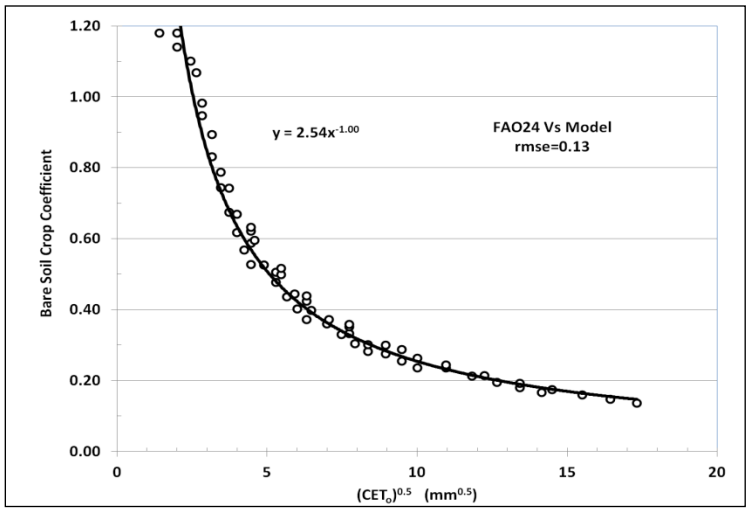
Crop evapotranspiration is estimated as the product of ETo and a Kc value. Crop coefficients are commonly developed by measuring ETc, calculating ETo, and determining the ratio Kc = ETc / ETo. While crop coefficients are continuously developed and evaluated, Cal-SIMETAW was designed for easy updates of both Kc and crop growth information. The Kc values and corresponding growth dates are included by crop in the model. These dates and Kc values are used to estimate daily Kc values during a season.

Estimating Bare Soil Crop Coefficient Values

A soil evaporation Kc value, based on ETo and rainfall frequency, is needed as a minimum (base line) for estimating ETc. The Kc values used to estimate bare soil evaporation are determined by using a two-stage soil evaporation method reported by Stroonsnjider (1987), and refined by Snyder et al. (2000) and Ventura et al. (2006). This method provides Kc values as a function of an ETo rate and wetting frequency that are similar to those published by Doorenbos and Pruitt (1977). Computation of the bare soil Kc values is somewhat complicated, so a simplified method was recently developed by comparing the Kc values generated using the model from Ventura et al. (2006) with the square root of the cumulative ETo.

The soil evaporation values in the model used a hydraulic factor $\beta = 2.6$. The results are shown in Figure 4. This method provides a good estimate of a typical bare soil Kc value is obtainable. Figure 4 shows a bare soil Kc curve as a function of the square root of the cumulative reference evapotranspiration (CETo).

Figure 4. Bare-Soil Crop Coefficient Curve as a Function of the Square Root of CETo



Note:
CETo = cumulative reference evapotranspiration, rmse = root mean square error

To determine the baseline Kc from rainfall frequency, the $(CETo)^{0.5}$ used to determine the bare soil crop coefficient is calculated as:

$$(CETo)^{0.5}\sqrt{D_{BR} * ETo} \quad (4)$$

where D_{BR} is the number of days between rainfall events, and ETo is the mean daily ETo rate during the non-rainfall period. Then, the bare-soil Kc value during that period is estimated as:

$$Kc = \frac{2.54}{\sqrt{CETo}} \quad (5)$$

During the off-season, the bare-soil Kc value is used to estimate the soil evaporation. During the season, the bigger of the bare-soil Kc, or the Kc based on the crop Kc values, is used to calculate the crop evapotranspiration as:

$$ETc = ETo * Kc \quad (6)$$

Estimates of Crop Evapotranspiration for Rice in the Sacramento Valley

Cal-SIMETAW requires crop, soil, and climate data to perform daily soil water balances that are used to determine ETc and ETaw for agricultural crops by various DAU/county within California. In the Cal-SIMETAW model, soil and climate databases were developed to spatially characterize ETc and

ETaw. Using mean soil characteristics, climate, and ETo information from the 4 km x 4 km grid, Cal-SIMETAW estimates the mean soil characteristics and ETo information by DAU/county. Although Cal-SIMETAW has soil characteristic information and computes ETo on a 4 km x 4 km grid spacing, crop planting information is limited to the DAU/county. The DAU/county is the smallest unit for calculation of the ETc for a particular crop.

Using GIS, a weighted-mean value of ETo for irrigated land was determined by DAU/county. The crop coefficient curve for rice was determined based on the percentages of the season to various growth stages, Kc values at critical growth points, and start and end dates during the season. The Kc curves were used with the daily weighted-mean ETo estimates to calculate daily, monthly, and seasonal ETc for rice for each of the 19 DAU/counties in the Sacramento Valley from 1987 to 2016. The seasonal estimates of ETc on each DAU/county within the valley were averaged over the 1987–2016 period to obtain long-term average ETc estimates. These time-averaged estimates of crop evapotranspiration, and the number of acres of rice during 2014 in each of the DAU/counties, were used to determine a weighted-mean estimate of seasonal ETc for rice for the Sacramento Valley. Figure 5 shows the geographical locations of rice planted, by DAU/county, within the Sacramento Valley during 2014.

Table 2 shows the rice acreages planted during 2014, the 30-year average of seasonal ETc obtained from the described method, the average seasonal estimates of ETc during dry years, and the 30-year average precipitation by DAU/county and Sacramento Valley during the season.

The results from this study, presented in Table 2, indicate that the model predictions of seasonal crop evapotranspiration for rice for the Sacramento Valley over the 30-year periods matched reasonably well with the average seasonal measurements of ETc in 2012–2013 developed by Snyder (2014) at UC Davis. The mean ETc estimates were 34.35 inches and 34.0 inches for this study's model and Snyder's, respectively.

Figure 5. Study Area from ArcGIS Showing Rice Acreage for the 19 DAU/Counties in the Sacramento Valley (2014)

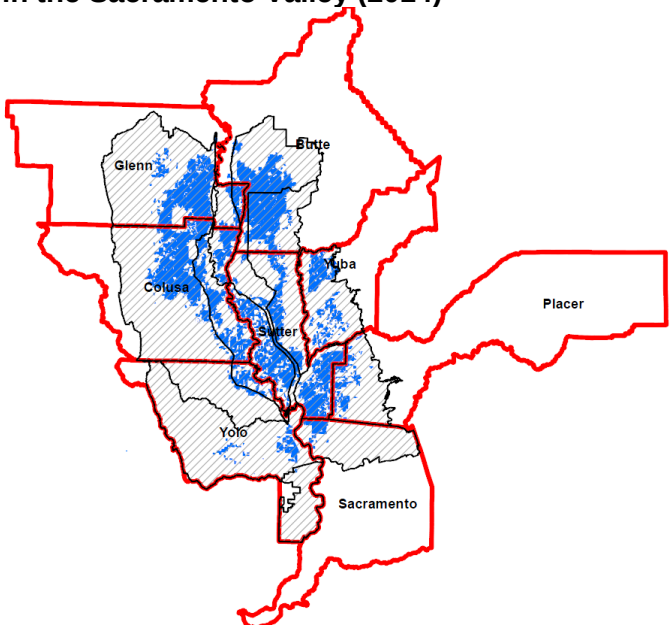


Table 2. Rice Acreages and 30-Year Averages of ETc, and Precipitation during the Growing Season by DAU/County in the Sacramento Valley

DAU/County	Planted Area (acres)	30-Year Average ETc (inches)	Dry Year Average ETc (inches)	30-Year Average Seasonal Precipitation (inches)
162-Yolo	7,903	34.45	34.98	1.84
163-Colusa	62,858	32.95	33.58	1.90
163-Glenn	60,173	32.90	33.56	2.32
163-Yolo	1,332	34.09	34.74	1.79
164-Colusa	32,919	33.48	34.12	1.86
164-Yolo	12,295	34.39	35.03	1.78
165-Sutter	31,638	34.77	35.39	1.87
166-Butte	37,718	34.87	35.51	2.87
166-Glenn	8,044	34.34	34.99	2.48
166-Sutter	6,164	34.78	35.38	1.96
167-Colusa	16,976	33.44	34.11	1.97
167-Glenn	5,773	33.78	34.46	2.33
168-Butte	41,697	34.78	35.38	2.54
168-Sutter	21,277	35.23	35.83	2.13
171-Yuba	37,566	35.34	35.86	2.32
172-Placer	13,211	35.98	36.43	2.03
172-Sacramento	6,798	36.34	36.81	1.79
172-Sutter	36,891	36.25	36.41	1.89
186-Yolo	3,749	35.93	36.70	1.73
Sacramento Valley	444,983	34.35	34.92	**2.16**

Notes:
DAU = detailed analysis unit, ETc = crop evapotranspiration

Comparison of Annual and 30-Year Average Estimates Crop Evapotranspiration for Rice by Detailed Analysis Unit/County

ETc data from 1987 to 2016 was analyzed based on Cal-SIMETAW to determine ETc averages in 19 DAU/counties within the Sacramento Valley. ETc averages were used to determine the annual variations from the mean for each DAU/county. Tables 3a through 3c present annual variations of ETc by DAU/county from 1987 to 2016.

Table 3a. Percentage of Annual Variations of Mean ETc by DAU/County (1987–2016)

Year	162-Yolo (%)	163-Colusa (%)	163-Glenn (%)	163-Yolo (%)	164-Colusa (%)	164-Yolo (%)
1987	1.29	5.02	2.02	1.73	5.63	1.92
1988	2.37	2.08	1.09	2.56	3.38	2.92
1989	-0.42	-0.83	-2.36	-0.51	0.07	-0.23
1990	-0.08	-1.19	-1.35	-0.67	-1.27	-0.65
1991	-0.22	-1.91	-2.76	-0.96	-1.90	-0.68
1992	2.73	2.55	1.72	2.27	2.93	2.44
1993	-2.62	-3.48	-3.87	-3.53	-3.49	-3.26
1994	1.10	-0.85	-1.00	0.24	-1.08	0.56
1995	-2.26	-2.63	-3.40	-2.76	-2.84	-2.23
1996	1.32	0.70	-1.35	0.74	0.99	1.39
1997	1.89	-0.01	-1.71	1.56	0.43	1.95
1998	-6.68	-10.50	-10.65	-6.96	-9.63	-7.06
1999	-1.14	-4.91	-2.58	-2.07	-4.87	-1.96
2000	-1.00	-3.20	-3.32	-1.44	-2.42	-1.14
2001	5.15	2.61	3.96	4.75	2.91	4.82
2002	2.42	1.07	1.20	1.70	1.19	1.76
2003	3.57	1.82	1.53	3.24	2.17	3.18
2004	-0.03	-1.91	-1.90	-0.15	-1.33	0.05
2005	-1.41	-2.49	-1.66	-2.21	-2.63	-1.93
2006	-0.63	-0.69	-1.64	-0.51	-0.87	-1.04
2007	1.86	3.55	3.33	2.44	2.79	1.81
2008	4.72	5.86	4.80	5.21	5.29	4.65
2009	-1.50	0.55	4.49	-1.18	-0.52	-1.87
2010	-8.81	-6.84	-6.01	-8.42	-7.38	-8.87
2011	-10.86	-7.36	-6.43	-9.38	-7.78	-9.68
2012	0.66	4.42	5.49	1.97	3.70	1.82
2013	0.58	4.13	5.07	1.91	3.35	1.63
2014	3.16	5.67	7.07	4.22	5.21	3.87
2015	0.88	3.69	4.41	1.91	3.11	1.77
2016	0.49	0.62	1.13	0.82	0.60	0.56
Lowest	-10.86	-10.50	-10.65	-9.38	-9.63	-9.68
Highest	5.15	5.86	7.07	5.21	5.63	4.82

Notes:
DAU = detailed analysis unit, ETc = crop evapotranspiration

Table 3b. Percentage of Annual Variations of Mean ETc by DAU/County (1985–2014)

Year	165-Sutter (%)	166-Butte (%)	166-Glenn (%)	166-Sutter (%)	167-Colusa (%)	167-Glenn (%)
1987	3.37	5.43	5.41	4.62	6.98	5.09
1988	3.68	3.73	3.37	4.23	4.03	2.79
1989	0.74	2.06	1.17	1.28	0.62	0.35
1990	-0.26	-0.41	-0.56	0.08	-1.36	-1.18
1991	-0.30	1.44	-0.31	-0.10	-2.10	-1.31
1992	3.19	4.79	3.82	3.88	3.35	3.09
1993	-2.46	-0.22	-2.04	-2.00	-3.63	-2.99
1994	1.16	2.35	1.13	1.39	-1.64	0.03
1995	-1.24	-0.08	-0.76	-0.93	-3.00	-1.81
1996	2.52	2.14	1.25	2.73	0.51	0.49
1997	2.82	3.13	2.30	2.50	-0.14	1.33
1998	-7.16	-7.31	-7.96	-7.61	-10.01	-8.87
1999	-2.31	1.35	-0.39	-2.64	-4.70	-1.81
2000	-0.47	1.33	0.34	-0.44	-2.28	-0.73
2001	4.98	7.00	6.06	4.89	3.16	4.97
2002	2.18	3.88	3.28	2.44	1.61	2.49
2003	3.26	2.88	3.11	3.35	2.46	2.62
2004	0.53	1.15	0.87	0.57	-1.05	-0.07
2005	-1.36	-3.04	-1.88	-1.42	-2.70	-2.15
2006	-2.36	-6.62	-5.17	-3.30	-1.84	-3.29
2007	0.56	-2.12	-0.51	0.13	2.48	1.06
2008	3.29	-0.26	1.51	2.67	4.59	3.15
2009	-3.03	-4.28	-3.12	-3.39	-0.50	-1.51
2010	-9.66	-11.32	-10.07	-10.01	-7.53	-8.49
2011	-10.45	-11.54	-10.22	-10.59	-7.62	-8.62
2012	1.12	0.32	1.74	0.88	3.87	3.09
2013	0.72	-0.31	0.98	0.46	3.37	2.51
2014	2.96	2.66	3.62	2.80	5.22	4.75
2015	0.87	-0.57	0.69	0.61	3.07	1.99
2016	-0.68	-3.09	-2.11	-1.24	0.19	-0.84
Lowest	**-10.45**	**-11.54**	**-10.22**	**-10.59**	**-10.01**	**-8.87**
Highest	**4.98**	**7.00**	**6.06**	**4.89**	**6.98**	**5.09**

Notes:
DAU = detailed analysis unit, ETc = crop evapotranspiration

Table 3c. Percentage of Annual Variations of Mean ETc by DAU/County (1987–2016)

Year	168-Butte (%)	168-Sutter (%)	171-Yuba (%)	172-Placer (%)	172-Sacramento (%)	172-Sutter (%)	186-Yolo (%)
1987	5.18	3.17	2.53	2.48	3.33	3.00	1.97
1988	3.80	3.79	3.42	3.71	5.09	4.57	3.77
1989	2.02	1.55	1.39	0.01	1.21	1.42	0.83
1990	0.06	0.12	-0.07	-0.02	1.43	0.92	1.36
1991	0.29	0.50	0.41	0.18	1.34	1.06	1.37
1992	4.27	3.69	3.50	3.31	4.31	4.02	3.54
1993	-1.76	-1.59	-1.63	-1.83	-0.77	-1.17	-0.40
1994	2.10	2.61	2.80	1.90	2.77	2.74	2.59
1995	0.47	0.48	0.59	-0.83	-0.46	-0.12	-0.59
1996	2.22	3.84	3.96	3.04	3.78	3.75	3.99
1997	3.09	4.67	4.99	3.68	3.39	4.09	2.79
1998	-7.40	-6.38	-6.29	-5.52	-5.80	-5.37	-6.88
1999	-0.86	-2.14	-1.94	-0.55	0.18	-0.06	-1.03
2000	1.05	1.10	1.27	0.78	0.53	0.93	-0.74
2001	6.63	5.85	6.09	6.13	5.99	6.45	5.19
2002	3.41	2.69	2.60	2.88	2.62	3.17	2.90
2003	3.53	3.50	3.14	3.68	3.80	4.20	3.68
2004	2.08	1.86	2.33	1.67	0.56	1.77	0.09
2005	-1.84	-0.44	-0.62	-0.36	-0.88	-0.22	-0.79
2006	-5.62	-4.34	-4.10	-2.62	-3.01	-3.61	-2.26
2007	-1.67	-1.29	-1.68	-1.13	-1.37	-1.76	-0.50
2008	0.34	1.26	0.79	1.89	1.39	1.10	2.30
2009	-4.49	-4.89	-5.04	-3.89	-4.48	-5.00	-3.08
2010	-11.25	-11.39	-11.19	-10.46	-11.52	-11.69	-10.29
2011	-11.02	-11.62	-11.36	-11.82	-13.37	-13.40	-13.18
2012	0.74	-0.06	0.06	-0.47	-1.69	-1.59	-1.27
2013	-0.20	-0.73	-0.85	-1.22	-1.97	-2.09	-1.45
2014	2.71	1.93	2.48	2.21	1.24	1.07	1.95
2015	-0.22	-0.42	-0.62	-0.45	-1.55	-1.61	-0.75
2016	-2.78	-2.18	-1.72	-0.55	-1.24	-1.89	0.47
Lowest	**-11.25**	**-11.62**	**-11.36**	**-11.82**	**-13.37**	**-13.40**	**-13.18**
Highest	**6.63**	**5.85**	**6.09**	**6.13**	**5.99**	**6.45**	**5.19**

Notes:
DAU = detailed analysis unit, ETc = crop evapotranspiration

In comparing annual variations of ETc on each DAU/county from 1987 to 2016, the year 2011 has the lowest ETc, and 2001 has the highest values. The annual variations of all DAU/counties within the region ranged from +2.61 percent to +7.0 percent, and -13.4 percent to -6.40 percent, for 2001 and 2011, respectively. The temperature analyses indicate that the coldest and hottest years of the majority of the

DAU/counties were 2001 and 2011, respectively. Figures D1 through D19 (Appendix D) show plots of seasonal estimates of ETc for rice, 30-year averages of seasonal ETc, and precipitation during the 30-year averaging period, 1987–2016, by DAU/county in the Sacramento Valley.

ETc averages were also used to identify the highest and lowest ETc values in each DAU/county annually. In comparing seasonal ETc among the 19 DAU/counties, DAU 172/Sacramento County had the highest ETc, and DAU 163/Glenn County had the lowest amounts. The seasonal mean ETc estimates for the 30-year period for rice were 36.34 inches and 32.90 inches, in DAU 172/Sacramento County and DAU 163/Glenn County, respectively, a difference in values of approximately 9 percent. DAU 172/Sacramento County leads the Sacramento Valley region in total ETc at 5.0 percent higher than the region average. Conversely, the DAU 163/Glenn County has the least ETc, 4.0 percent less than the Sacramento Valley average. DAU/counties in Table 4 are sorted from highest to lowest ETc amounts.

Table 4. Seasonal Top 30-Year Average ETc by DAU/County in the Sacramento Valley

DAU/County	Planted Area (Acres)	30-Year Average ETc (Inches)
172-Sacramento	6,798	36.34
172-Sutter	36,891	36.25
172-Placer	13,211	35.98
186-Yolo	3,749	35.93
171-Yuba	37,566	35.34
168-Sutter	21,277	35.23
166-Butte	37,718	34.87
168-Butte	41,697	34.78
166-Sutter	6,164	34.78
165-Sutter	31,638	34.77
162-Yolo	7,903	34.45
164-Yolo	12,295	34.39
166-Glenn	8,044	34.34
163-Yolo	1,332	34.09
167-Glenn	5,773	33.78
164-Colusa	32,919	33.48
167-Colusa	16,976	33.44
163-Colusa	62,858	32.95
163-Glenn	60,173	32.90
Sacramento Valley	**444,983**	**34.35**

Notes:
DAU = detailed analysis units, ETc = crop evapotranspiration

Because water use is critical during dry years because of water shortages, the average seasonal ETc for rice on each of the 19 DAU/counties over the dry years was used to correct the long-term weighted average seasonal ETc for rice for the Sacramento Valley for dry climates. DAU/counties in Table 5 are sorted to identify the highest and lowest ETc values in each DAU/county annually. DAU 172/Sacramento County had the highest ETc, and DAU 163/Glenn County had the lowest amounts. The seasonal mean

ETc estimates for dry period for rice were 36.81 inches and 33.56 inches, in DAU 172/Sacramento County and DAU 163/Glenn County, respectively, a difference in values of approximately 9 percent. DAU 172/Sacramento County leads the Sacramento Valley region in total ETc at 5.0 percent higher than the region average. Conversely, the DAU 163/Glenn County has the least ETc, 4.0 percent less than the Sacramento Valley average.

Table 5. Seasonal Top Long-term Dry Year Average ETc by DAU/County in the Sacramento Valley

DAU/County	Planted Area (Acres)	Dry Year Average ETc (Inches)
172-Sacramento	6,798	36.81
186-Yolo	3,749	36.70
172-Placer	13,211	36.43
172-Sutter	36,891	36.41
171-Yuba	37,566	35.86
168-Sutter	21,277	35.83
166-Butte	37,718	35.51
165-Sutter	31,638	35.39
168-Butte	41,697	35.38
166-Sutter	6,164	35.38
164-Yolo	12,295	35.03
166-Glenn	8,044	34.99
162-Yolo	7,903	34.98
163-Yolo	1,332	34.74
167-Glenn	5,773	34.46
164-Colusa	32,919	34.12
167-Colusa	16,976	34.11
163-Colusa	62,858	33.58
163-Glenn	60,173	33.56
Sacramento Valley	**444,983**	**34.92**

Notes:
DAU = detailed analysis units, ETc = crop evapotranspiration

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Appendix A: Verification of Cal-SIMETAW Predictions of Reference Evapotranspiration using PRISM Data

The daily ETo values estimated by Cal-SIMETAW, using daily PRISM and Spatial CIMIS weather data, were validated against CIMIS ETo estimates from October 2004 to September 2010 at Davis, Gerber, Durham, and Nicolaus in the Sacramento Valley. The CIMIS weather stations at these sites were chosen because (1) they have high-quality weather data, (2) they contain longer weather records, and (3) they are distributed almost evenly across the Sacramento Valley. The results show reasonably good agreement among CIMIS-based estimates of ETo with those calculated from the calibrated HS equation using daily PRISM weather data, and with daily PM equation using Spatial CIMIS weather data. The four stations, their latitude and longitude information, and PRISM grid numbers are shown in Table A1.

Table A1. CIMIS Weather Stations used for Evaluating Reference Evapotranspiration Values

CIMIS Station Number	CIMIS Station Name	County	Latitude	Longitude	PRISM Grid (Row_Column)
6	Davis	Yolo	38.536	-121.776	99_62
8	Gerber	Tehama	40.044	-122.166	57_54
12	Durham	Butte	39.609	-121.824	69_61
30	Nicolaus	Sutter	38.871	-121.546	90_67

Note:
CIMIS = California Irrigation Management Information System, PRISM = Parameter elevation Regression on Independent Slopes Model

Cal-SIMETAW PRISM Reference Evapotranspiration vs. CIMIS Reference Evapotranspiration

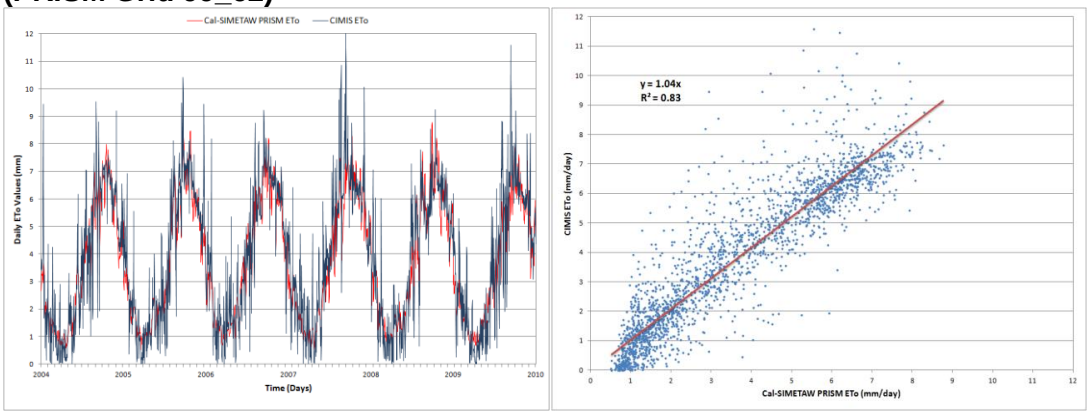
To determine the influence of limited weather data of PRISM for estimating ETo, using a calibrated HS equation for California, a comparison of the calibrated HS ETo from Cal-SIMETAW and CIMIS-based estimates of ETo with data from Davis, Gerber, Durham, and Nicolaus in the Sacramento Valley are shown in Figures A1 through A4. The results show that estimates of ETo for Water Years 2005–2010 closely approximate ETo values from CIMIS. For example, the mean ETo estimates from Davis for 2004–2010 were 3.69 mm and 3.88 mm with standard deviations of 2.16 mm and 2.43 mm for the calibrated HS model and CIMIS, respectively. The difference between the two approaches was small. But, the ETo would have been overestimated by the HS equation at this site because of clouds, or underestimated when they were influenced by a windy, arid environment. The results indicate that calibration of this equation was necessary in some microclimates. The calibrated form of the equation will compensate for the important climatic factors affecting ETo. Table A2, and Figures A1 through A4, show a close agreement exists between CIMIS-based estimates of ETo, and those of the Cal-SIMETAW model (HS ETo), in all cases. Figures A1 through A4 compare daily ETo estimates of the two methods at four sites within the Sacramento Valley from October 2004 to September 2010. They also show close agreement between CIMIS-based estimates of ETo, and those of the Cal-SIMETAW model using the historical PRISM temperature data.

Table A2. Cal-SIMETAW Model Predictions of ETo at CIMIS stations (Water Years 2005–2010)

CIMIS Station Name	Cal-SIMETAW PRISM ETo		Cal-SIMETAW Spatial CIMIS ETo		CIMIS ETo	
	Mean ETo (mm)	Standard. Deviation. (mm)	Mean ETo (mm)	Standard Deviation (mm)	Mean ETo (mm)	Standard Deviation (mm)
Davis	3.69	2.16	3.70	2.24	3.88	2.43
Gerber	3.59	2.09	3.64	2.17	3.80	2.38
Durham	3.94	2.28	3.61	2.15	3.46	2.12
Nicolaus	3.96	2.33	3.71	2.25	3.88	2.43

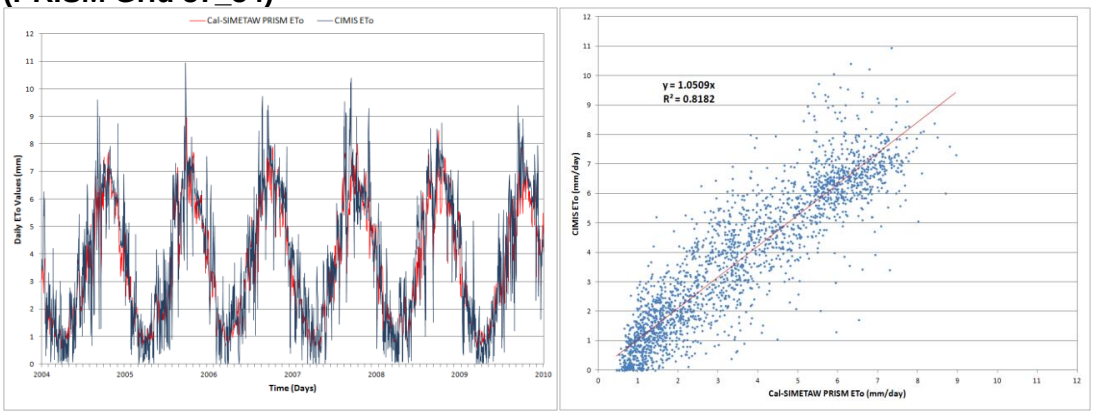
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, mm = millimeter, PRISM = Parameter elevation Regression on

Figure A1. Cal-SIMETAW PRISM ETo vs. CIMIS ETo at Davis, California (PRISM Grid 99_62)



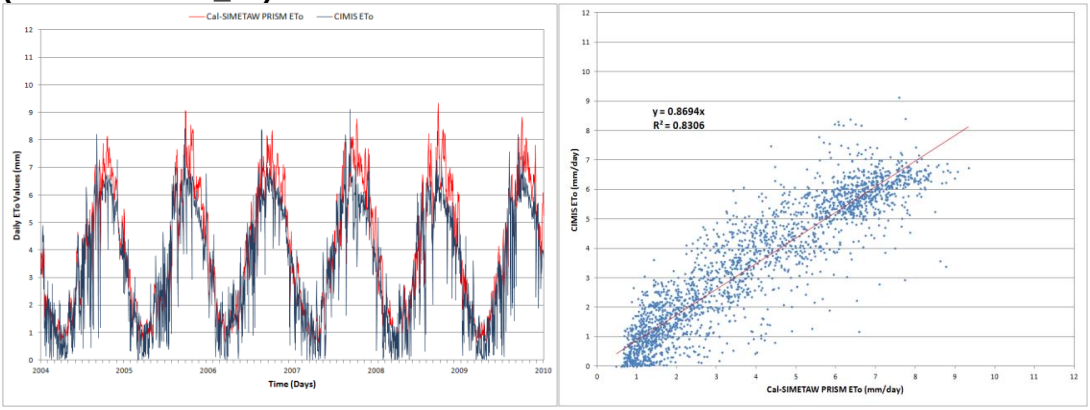
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A2. Cal-SIMETAW PRISM ETo vs. CIMIS ETo at Gerber, California (PRISM Grid 57_54)



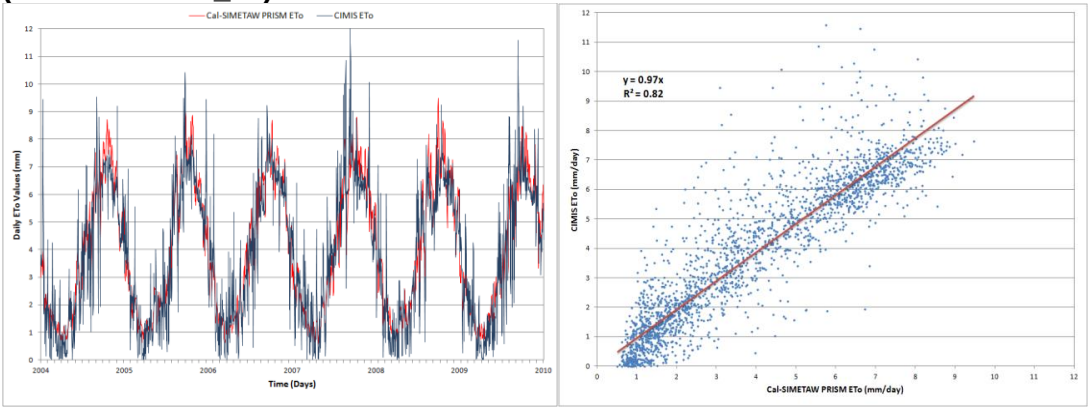
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A3. Cal-SIMETAW PRISM ETo vs. CIMIS ETo at Durham, California (PRISM Grid 69_61)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A4. Cal-SIMETAW PRISM ETo vs. CIMIS ETo at Nicolaus, California (PRISM Grid 90_67)

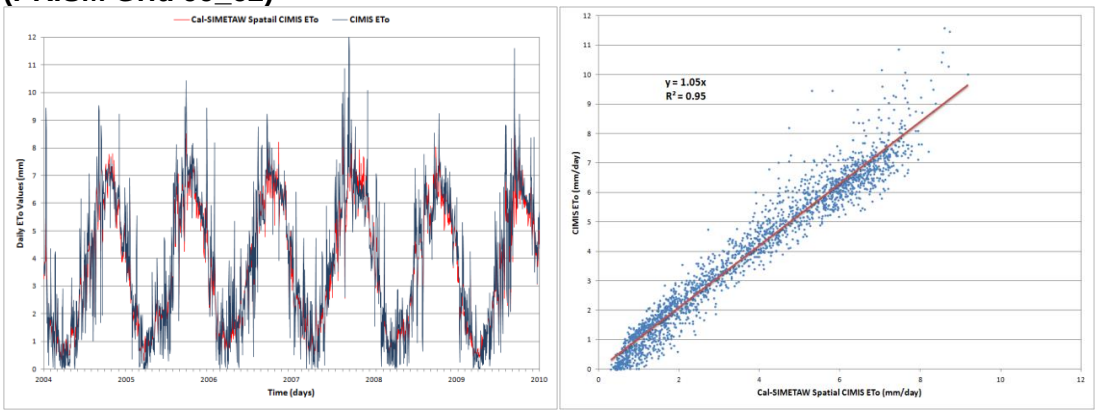


Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Cal-SIMETAW Spatial CIMIS Reference Evapotranspiration vs. CIMIS Reference Evapotranspiration

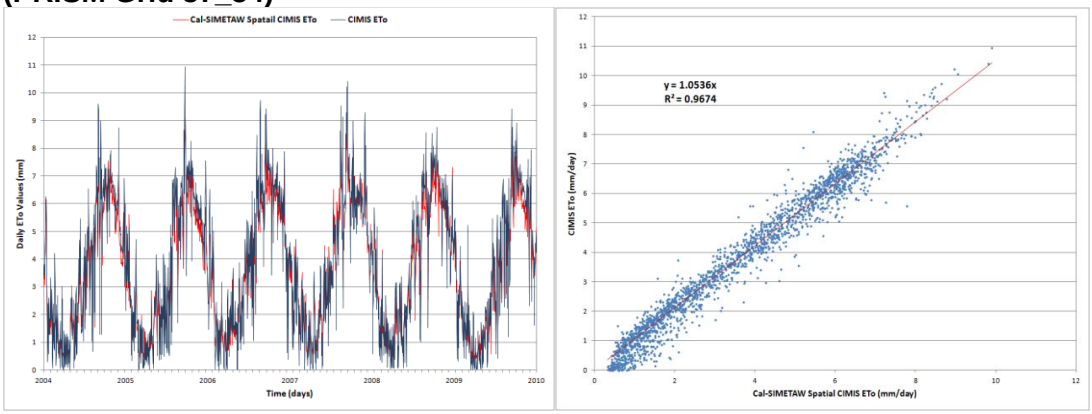
Cal-SIMETAW Spatial CIMIS ETo was also validated against CIMIS ETo estimates at the CIMIS stations within the Sacramento Valley from October 2004 to September 2010 (Figures A5 through A8).

Figure A5. Cal-SIMETAW Spatial CIMIS ETo vs. CIMIS ETo at Davis, California (PRISM Grid 99_62)



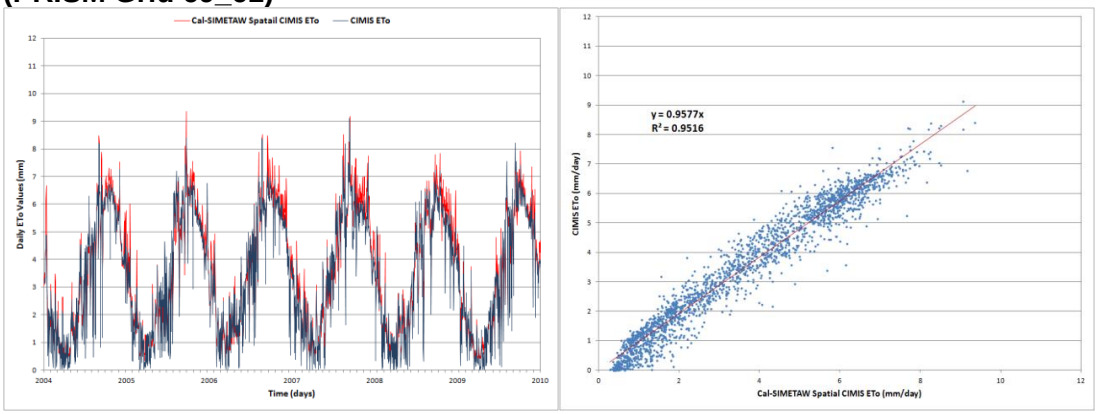
Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A6. Cal-SIMETAW Spatial CIMIS ETo vs. CIMIS ETo at Gerber, California (PRISM Grid 57_54)



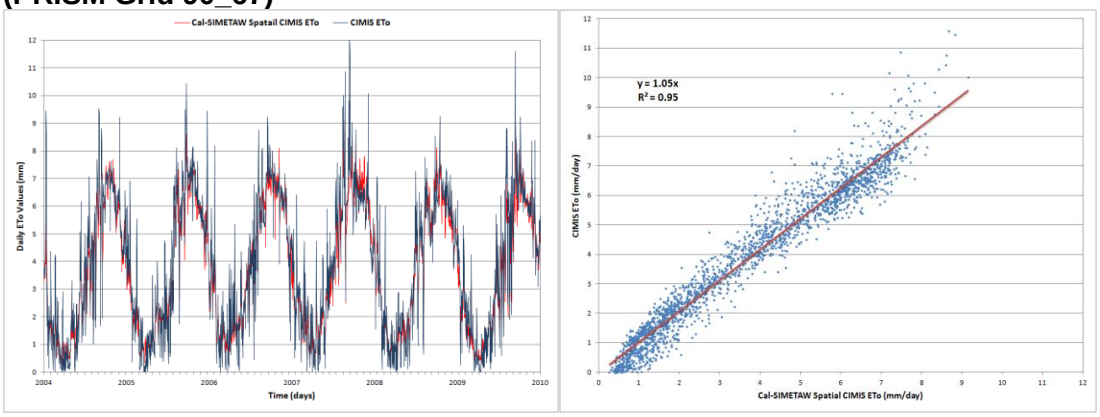
Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A7. Cal-SIMETAW Spatial CIMIS ETo vs. CIMIS ETo at Durham, California (PRISM Grid 69_61)



Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A8. Cal-SIMETAW Spatial CIMIS ETo vs. CIMIS ETo at Nicolaus, California (PRISM Grid 90_67)

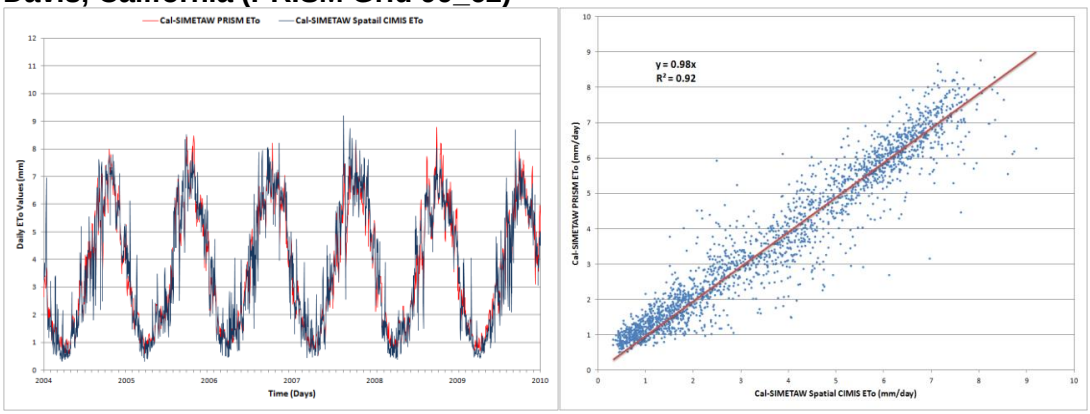


Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Cal-SIMETAW PRISM Reference Evapotranspiration vs. Spatial CIMIS Reference Evapotranspiration

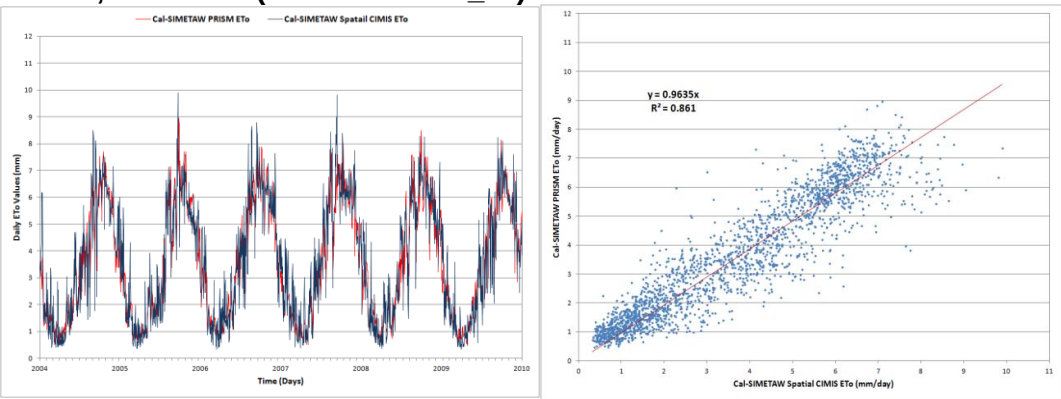
Cal-SIMETAW ETo estimates based on the calibrated HS equation were also compared with Spatial CIMIS ETo estimates at the same CIMIS sites within the Sacramento Valley from October 2004 to September 2010 (Figures A9 through A12).

Figure A9. Cal-SIMETAW PRISM ETo vs. Cal-SIMETAW Spatial CIMIS ETo at Davis, California (PRISM Grid 99_62)



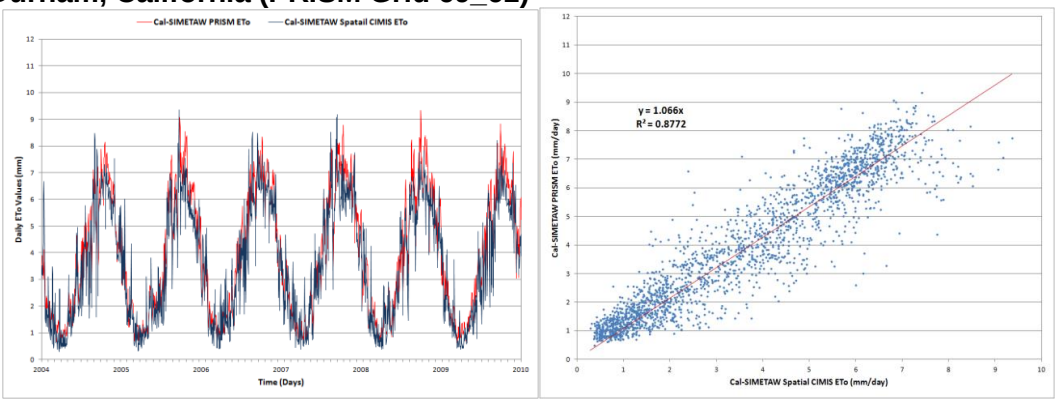
Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A10. Cal-SIMETAW PRISM ETo vs. Cal-SIMETAW Spatial CIMIS ETo at Gerber, California (PRISM Grid 57_54)



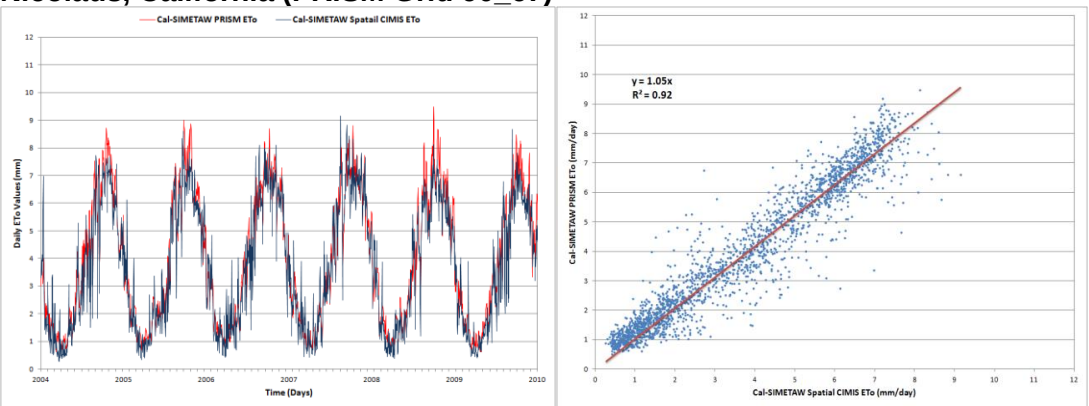
Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A11. Cal-SIMETAW PRISM ETo vs. Cal-SIMETAW Spatial CIMIS ETo at Durham, California (PRISM Grid 69_61)



Notes: Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure A12. Cal-SIMETAW PRISM ETo vs. Cal-SIMETAW Spatial CIMIS ETo at Nicolaus, California (PRISM Grid 90_67)



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Appendix B: Verification of Improved Weighted Mean PRISM Reference Evapotranspiration Data by Detailed Analysis Unit/County in the Sacramento Valley

The Cal-SIMETAW model was applied using both daily PRISM and Spatial CIMIS climate data from the model's database to estimate daily weighted-mean ETo data over the irrigated land for each DAU/county from 1981 to 2010. The results of the statistical data analysis in Table B1 indicate that estimates of ETo for all DAU/counties within the Sacramento Valley based on the Spatial CIMIS data, compared favorably with the Cal-SIMETAW PRISM ETo when the monthly correction factors were used. For example, the median ETo estimates in the Sacramento Valley from 2004 to 2010 were 3.72 inches and 3.71 inches with standard deviations of 2.46 inches and 2.47 inches for the calibrated HS equation and Spatial CIMIS model, respectively. The estimated ETo data using the PRISM climate data and a calibrated HS equation are nearly identical to Spatial CIMIS data.

Table B1. Cal-SIMETAW Model Predictions of ETo using Daily Spatial CIMIS and PRISM Climate Data (2005–2010)

DAU/County Number and Name	Cal-SIMETAW PRISM ETo		Cal-SIMETAW Spatial CIMIS ETo	
	Median ETo (inches)	Standard Deviation (inches)	Median ETo (inches)	Standard Deviation (inches)
162-Yolo	4.01	2.50	3.97	2.51
163-Colusa	4.07	2.42	3.96	2.42
163-Glenn	4.06	2.39	4.05	2.41
163-Yolo	4.01	2.49	3.96	2.50
164-Colusa	4.11	2.45	3.97	2.45
164-Colusa	3.99	2.51	4.02	2.52
165-Sutter	4.05	2.50	3.98	2.51
166-Butte	4.05	2.43	3.95	2.43
166-Glenn	4.09	2.42	3.96	2.42
166-Sutter	4.08	2.48	3.97	2.49
167-Colusa	4.13	2.43	3.96	2.43
167-Glenn	4.10	2.41	3.96	2.42
168-Butte	4.07	2.43	3.94	2.44
168-Sutter	4.07	2.48	3.97	2.49
171-Yuba	4.05	2.49	3.96	2.50
172-Placer	4.04	2.57	4.01	2.58
172-Sacramento	4.04	2.59	4.01	2.60
172-Sutter	4.04	2.57	4.00	2.58
186-Yolo	4.05	2.59	4.00	2.60
Sacramento Valley	**4.06**	**2.46**	**3.98**	**2.47**

Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis units, ETo = reference evapotranspiration

Figures B1 through B57 show comparisons of daily and monthly weighted-mean ETo estimates by DAU/county based on the PRISM and Spatial CIMIS climate data from January 2005 to September 2010. Estimates of 5-year means of daily ETo based on the calibrated HS equation and standardized PM equation for each DAU/county for the period 2005-2010, are also compared. Five years of daily weather data from Spatial CIMIS and PRISM that cover the Sacramento Valley on a 4 km x 4 km grid spacing were used in the Cal-SIMETAW model to calculate daily weighted-mean ETo by DAU/county. The ETo data computed using the daily climate data, (i.e., Tmax and Tmin) from PRISM were compared with the ETo data from Spatial CIMIS by DAU/county within the valley. Figures B1 through B57 show close agreement between Spatial CIMIS-based estimates of ETo and those of the calibrated HS equation during the 2005–2010 period. In all DAU/counties, the comparisons between Spatial CIMIS ETo and PRISM ETo data were good.

Figure B1. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 162/Yolo County (January 2005–September 2010)

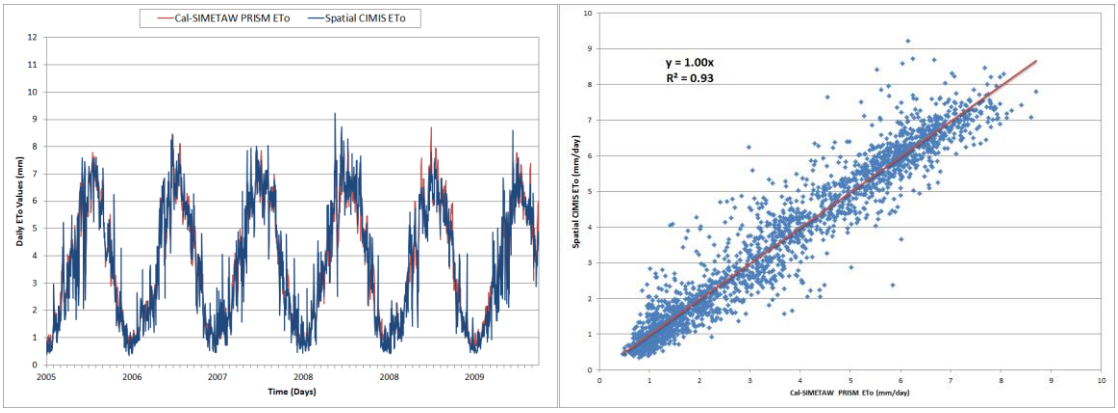


Figure B2. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 162/Yolo County (January 2005–September 2010)

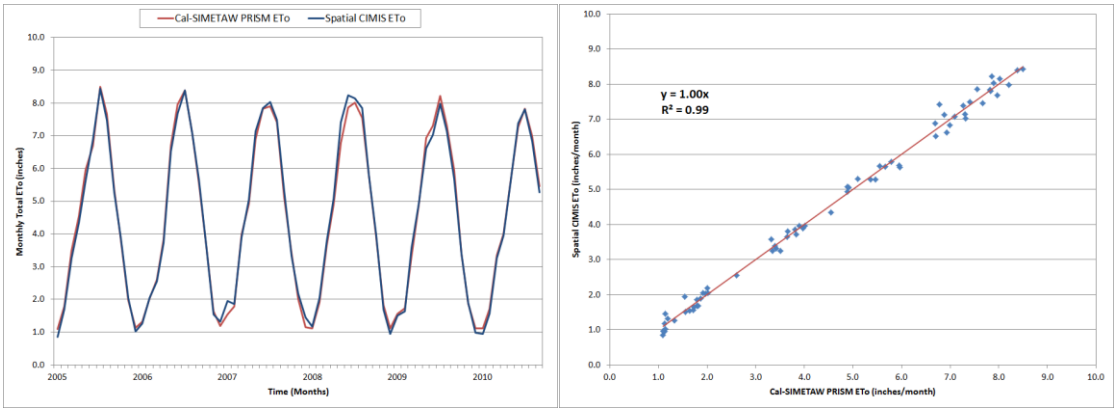
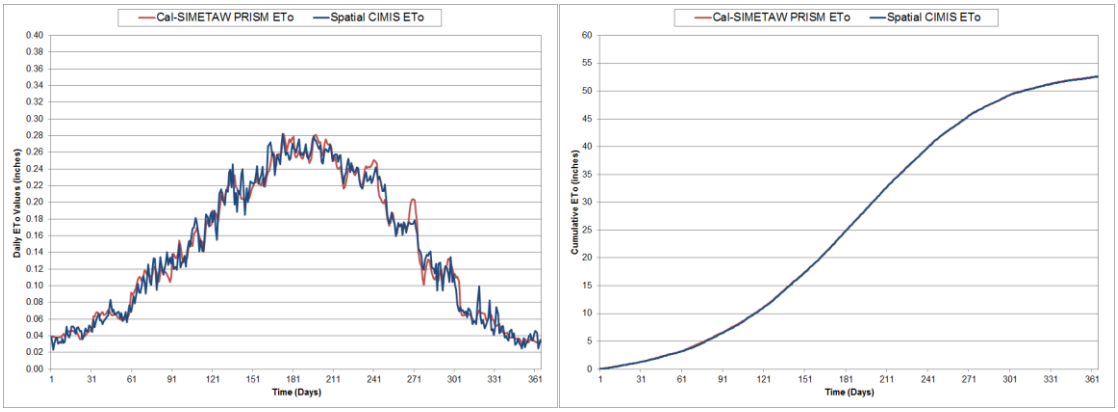


Figure B3. Daily Estimated Weighted Mean ETo and cumulative ETo for PRISM and Spatial CIMIS in DAU 162/Yolo County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B4. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 163/Colusa County (January 2005–September 2010)

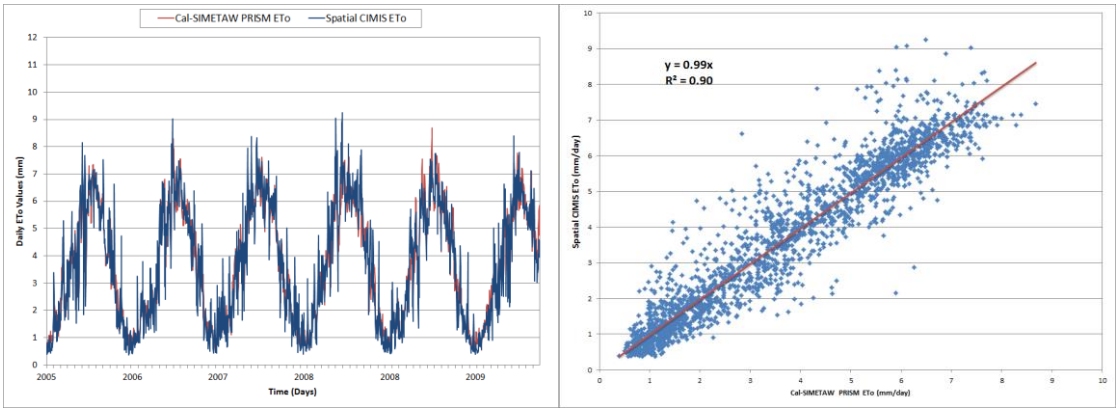


Figure B5. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 163/Colusa County (January 2005–September 2010)

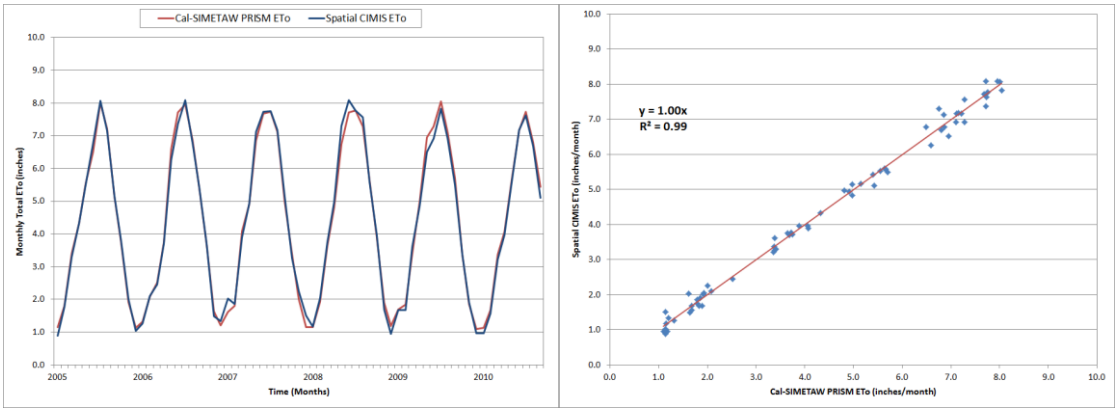
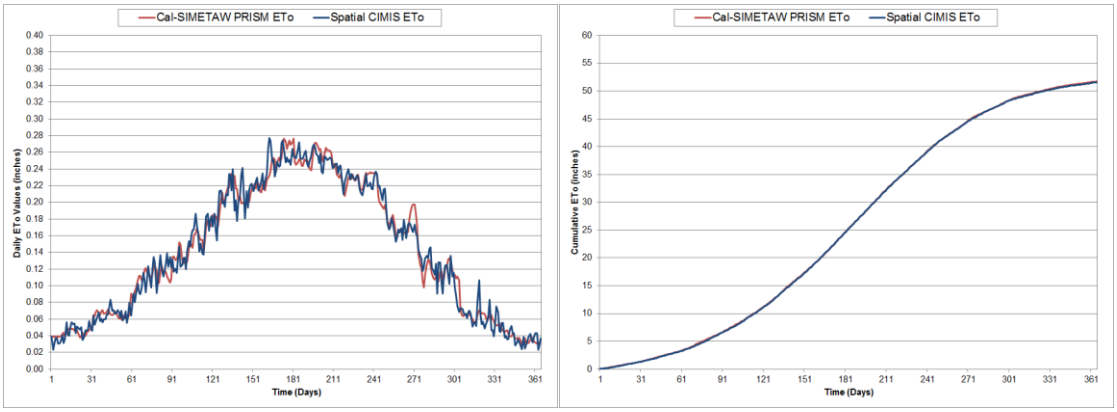


Figure B6. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 163/Colusa County (January 2005–September 2010)



Notes:
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Figure B7. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 163/Glenn County (January 2005–September 2010)

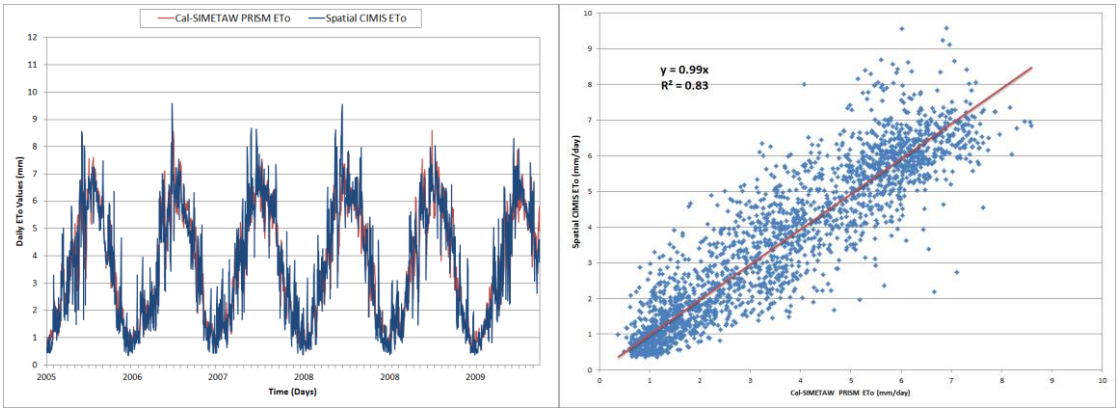


Figure B8. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 163/Glenn County (January 2005–September 2010)

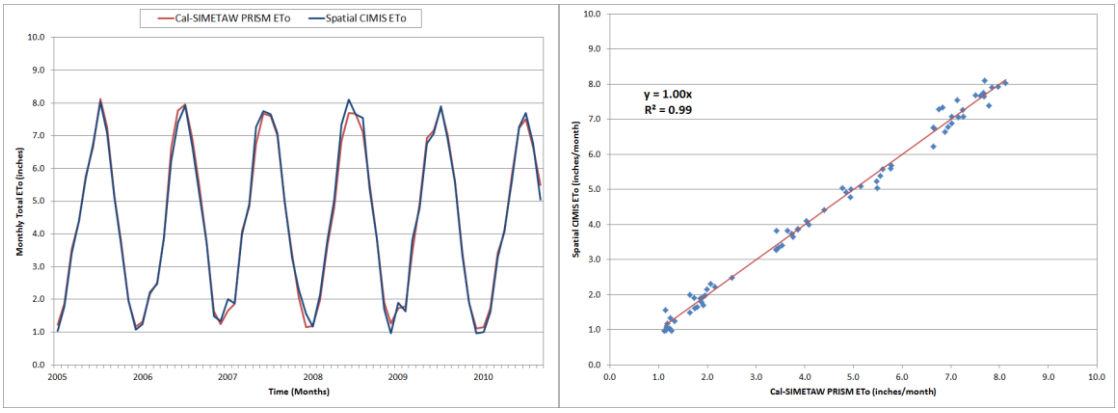
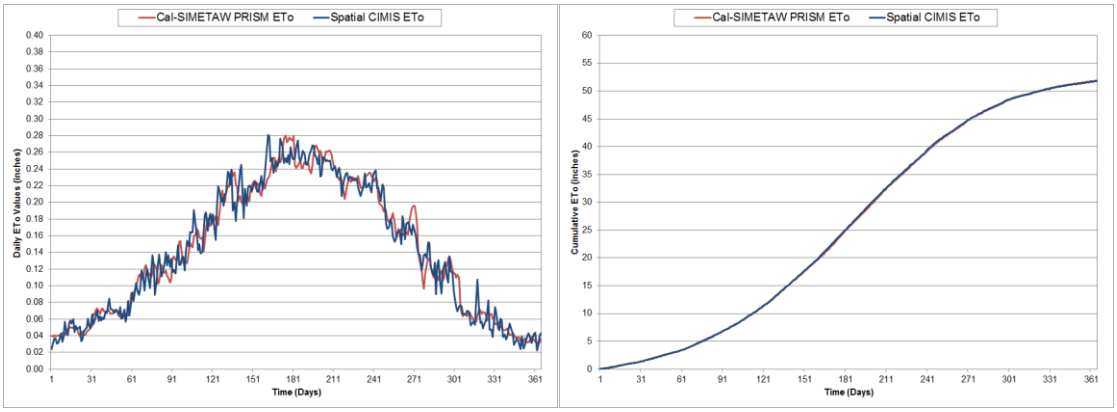


Figure B9. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 163/Glenn County (January 2005–September 2010



Notes:
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Figure B10. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 163/Yolo County (January 2005–September 2010)

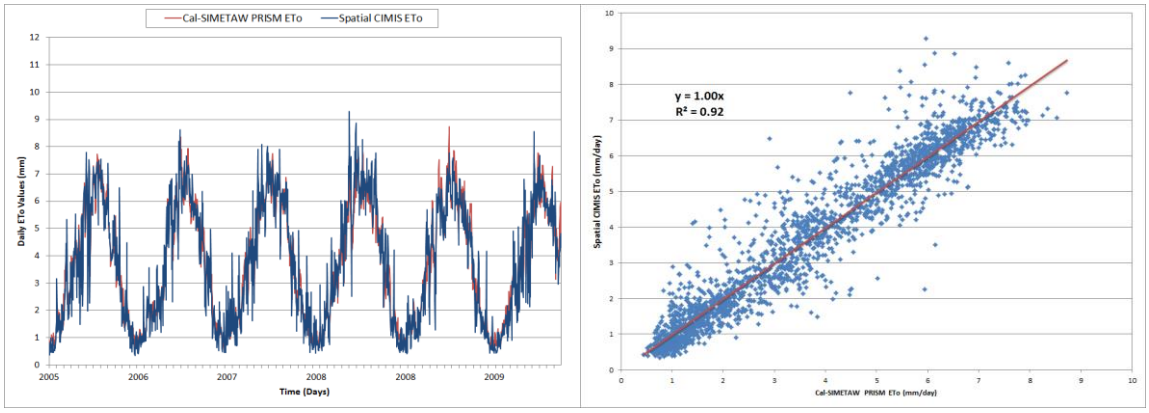


Figure B11. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 163/Yolo County (January 2005–September 2010)

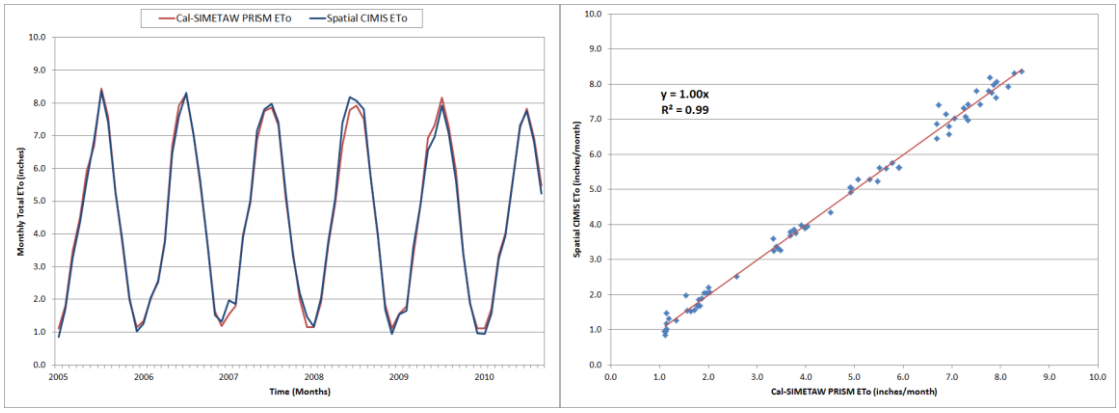
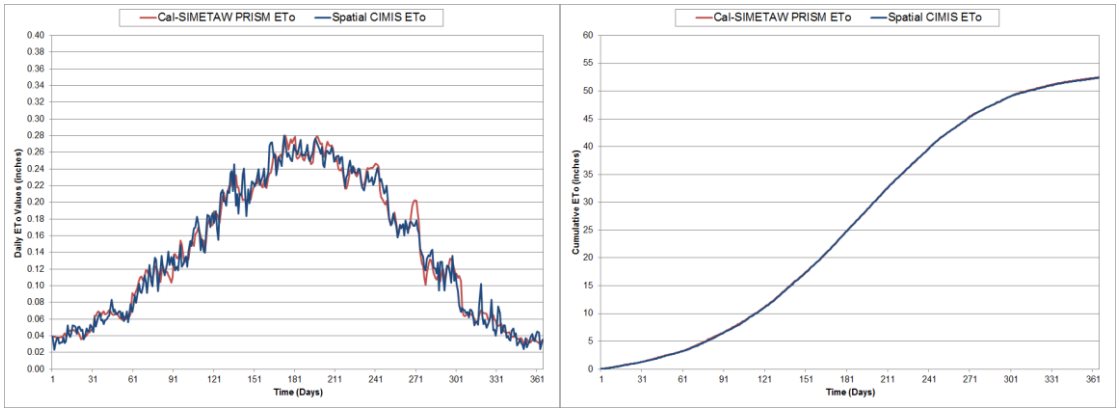


Figure B12. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 163/Yolo County (January 2005–September 2010)



Notes:
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Figure B13. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 164/Colusa County (January 2005–September 2010)

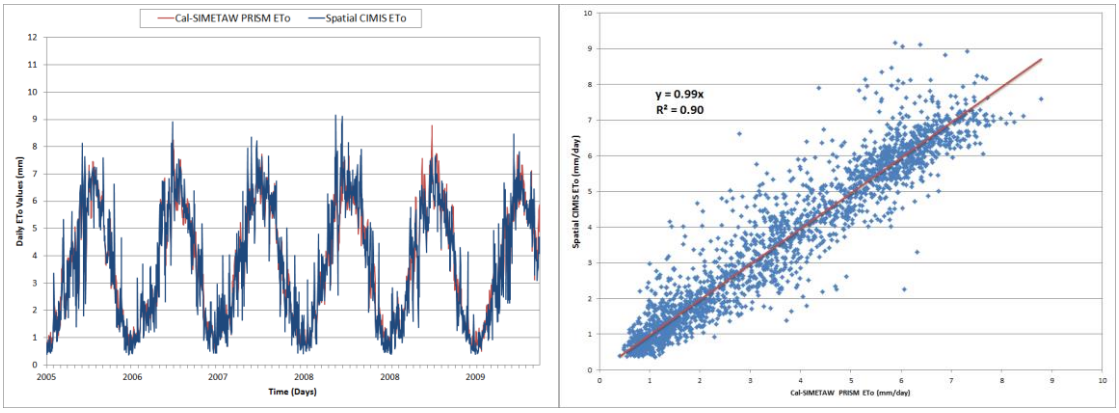


Figure B14. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 164/Colusa County (January 2005–September 2010)

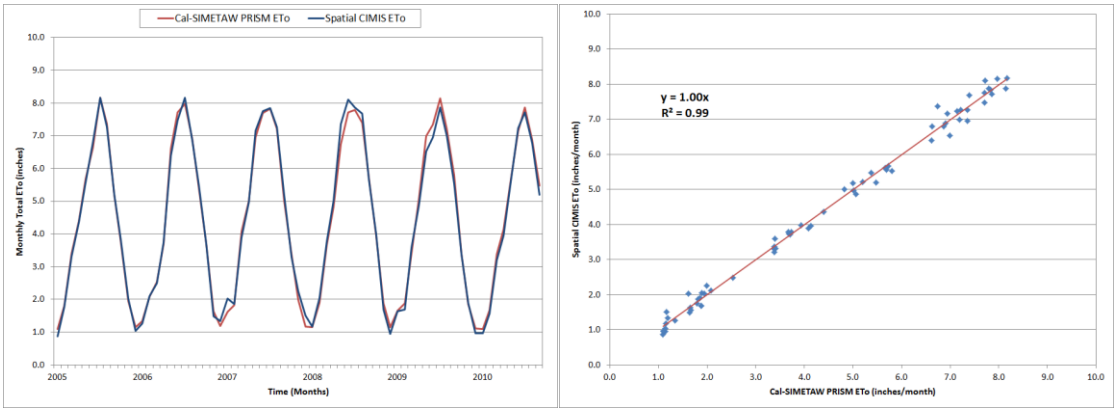
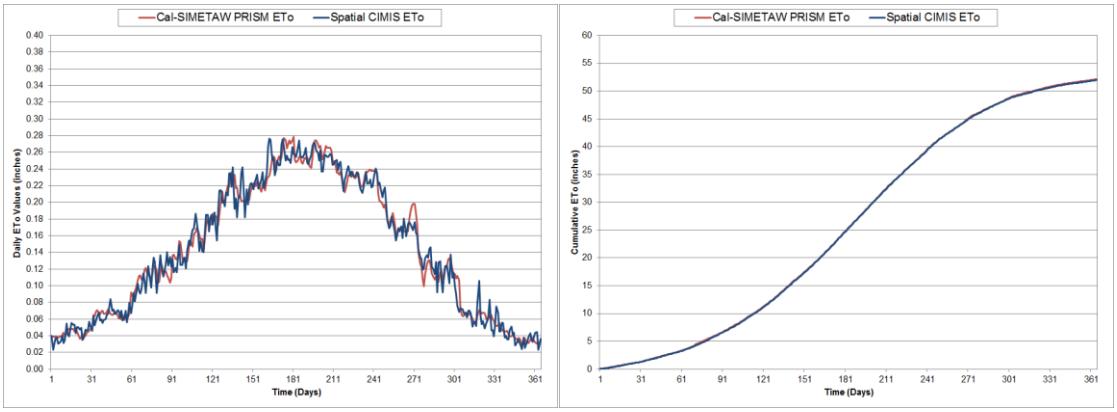


Figure B15. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 164/Colusa County (January 2005–September 2010)



Notes:
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Figure B16. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 164/Yolo County (January 2005–September 2010)

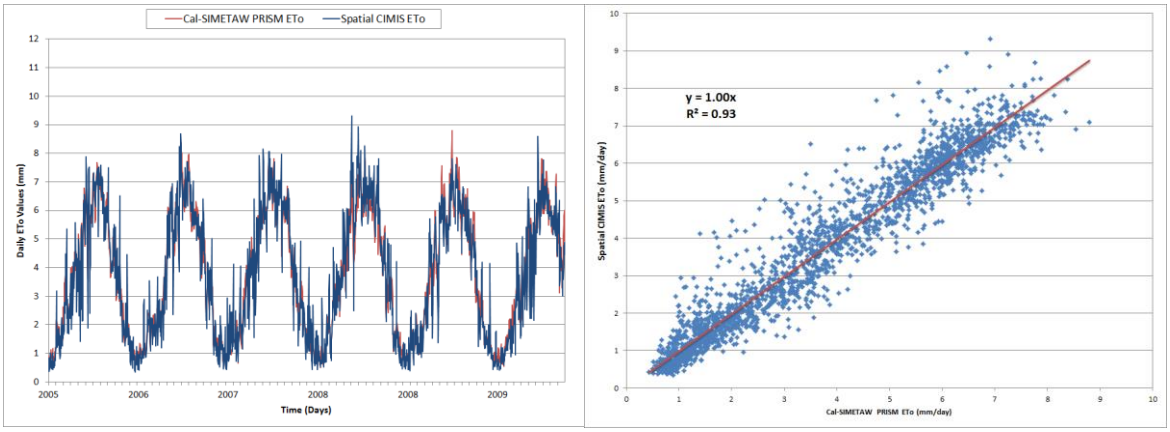


Figure B17. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 164/Yolo County (January 2005–September 2010)

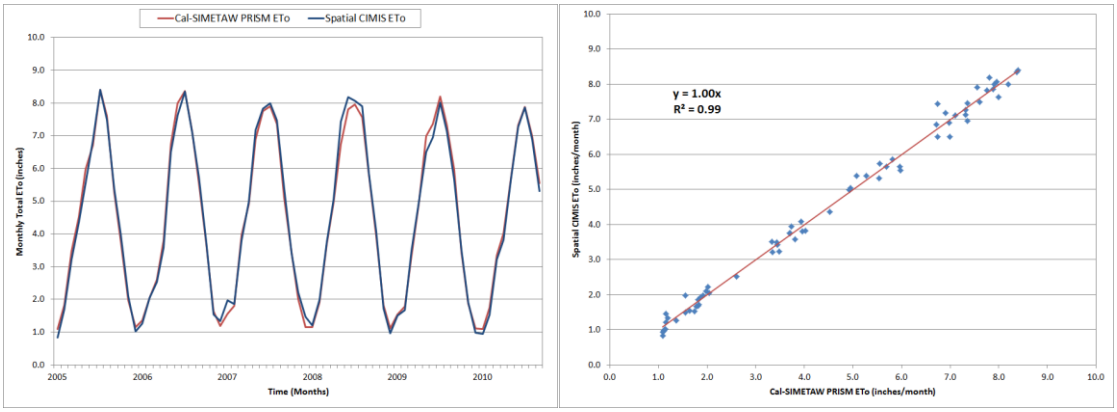
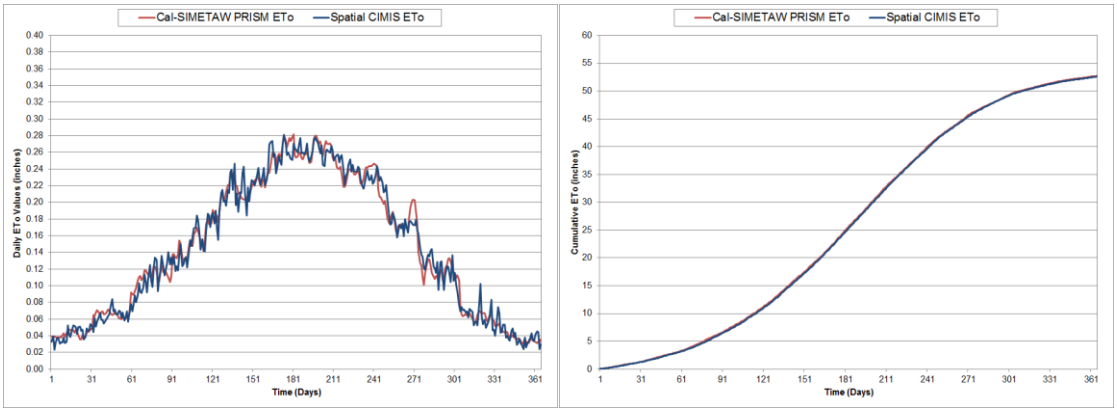


Figure B18. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 164/Yolo County (January 2005–September 2010)



Notes:

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Figure B19. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 165/Sutter County (January 2005–September 2010)

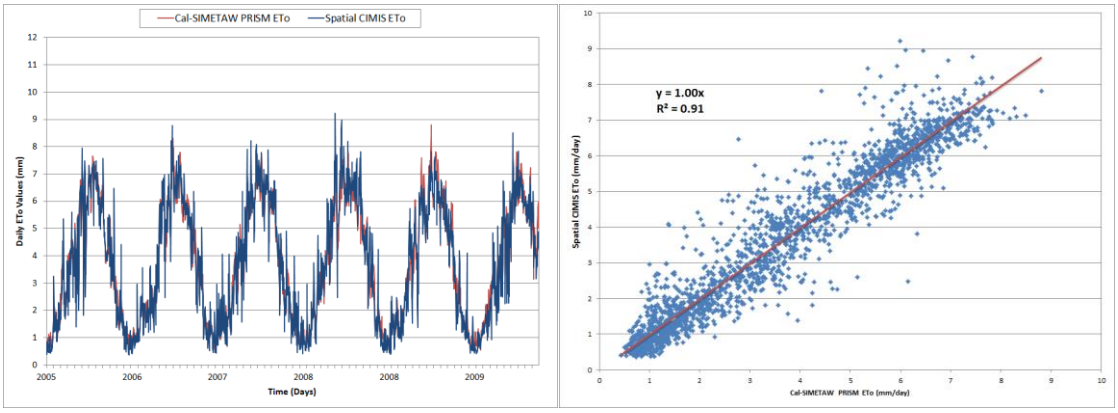


Figure B20. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 165/Sutter County (January 2005–September 2010)

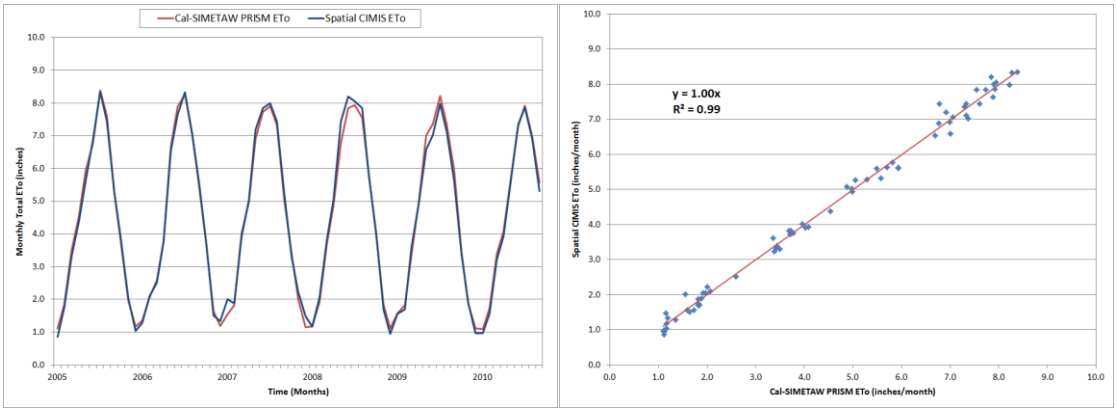
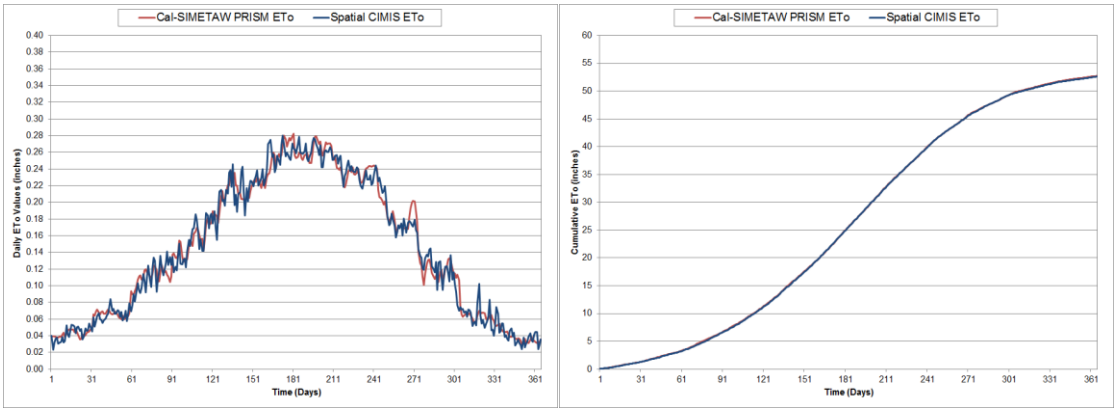


Figure B21. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 165/Sutter County (January 2005–September 2010)



Notes:
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Figure B22. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 166/Butte County (January 2005–September 2010)

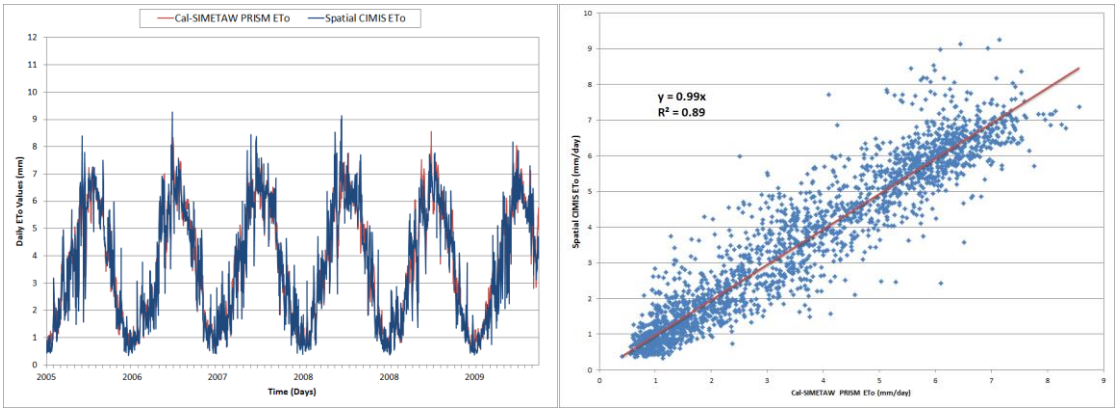

Figure B23. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 166/Butte County (January 2005–September 2010)

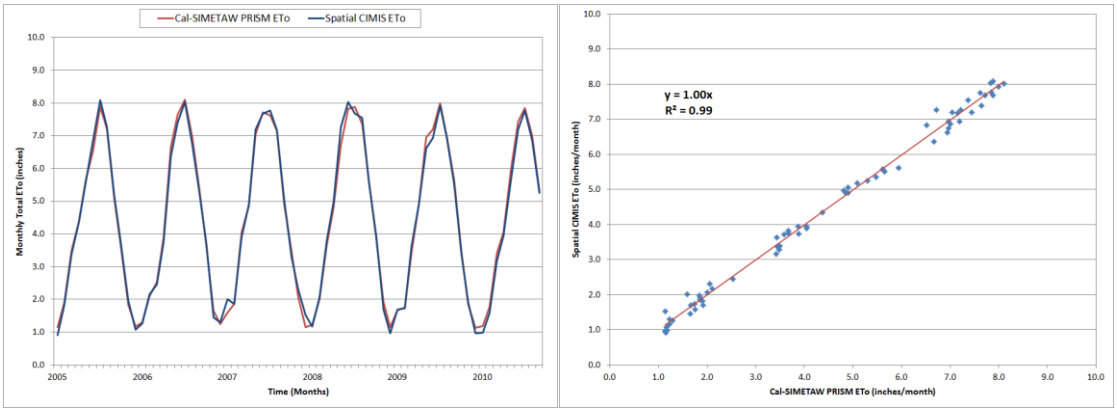

Figure B24. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 166/Butte County (January 2005–September 2010)

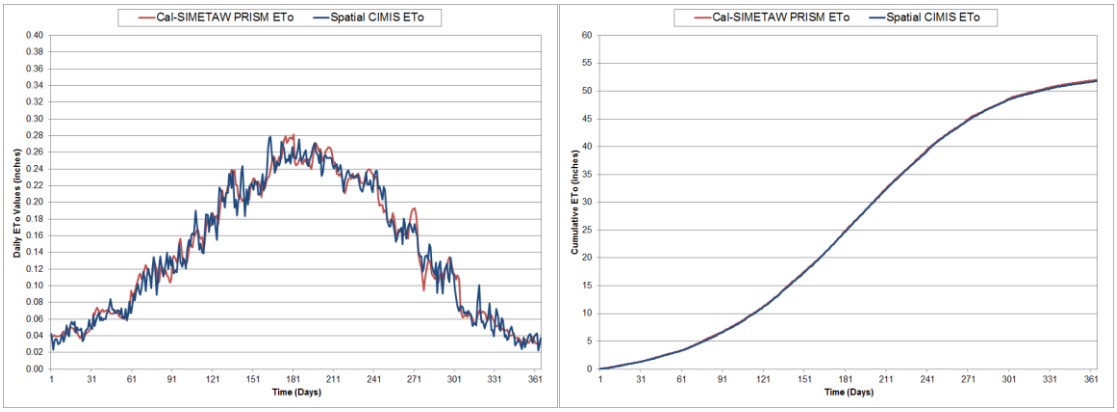

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Figure B25. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 166/Glenn County (January 2005–September 2010)

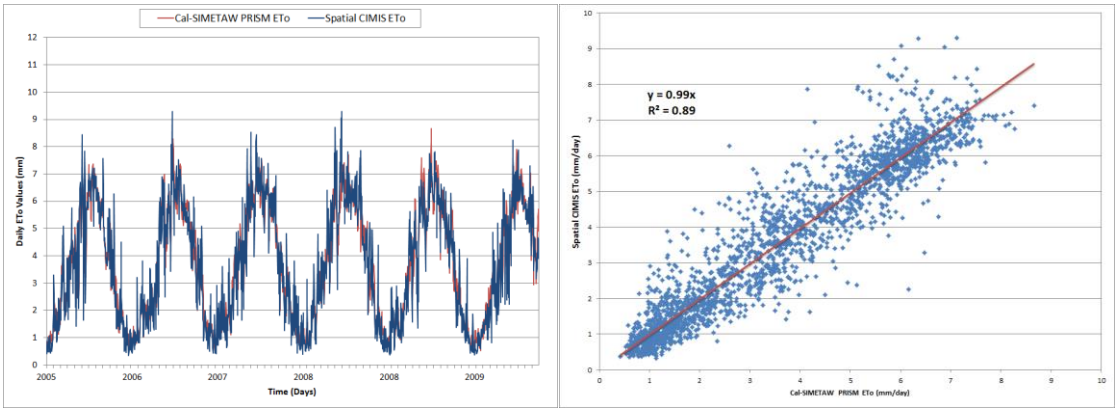

Figure B26. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 166/Glenn County (January 2005–September 2010)

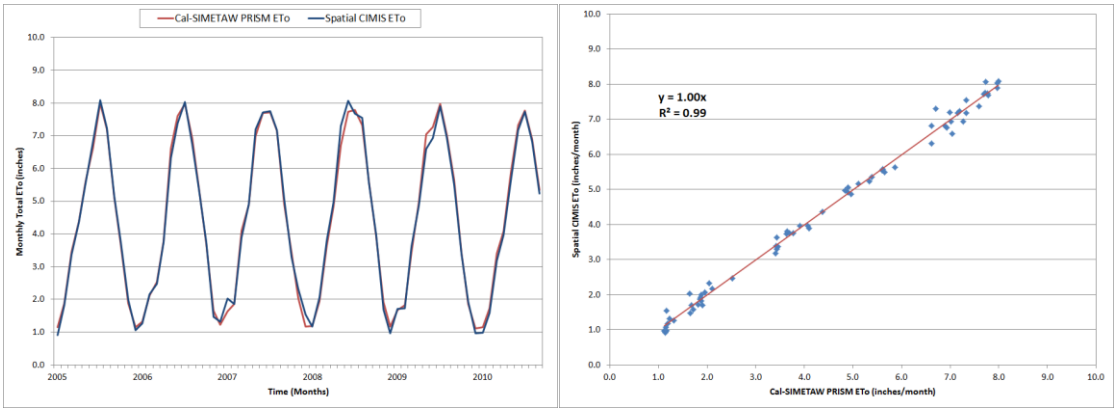

Figure B27. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 166/Glenn County (January 2005–September 2010)

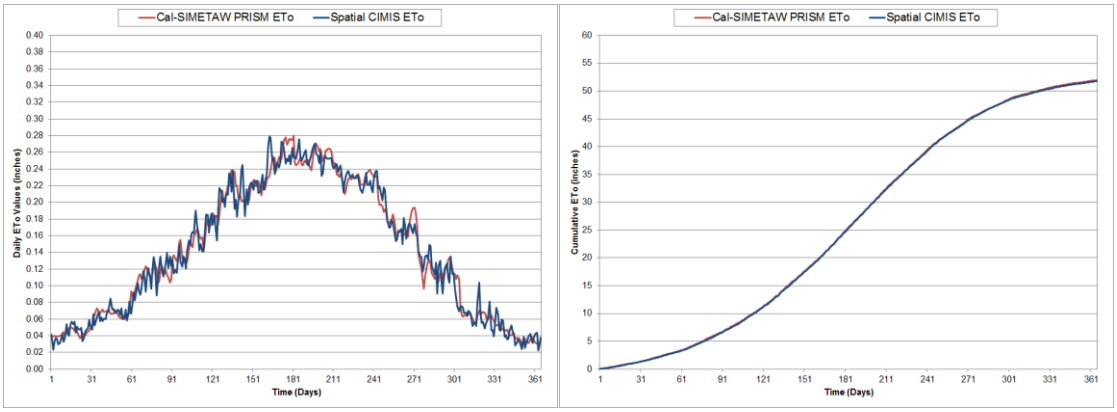

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Figure B28. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 166/Sutter County (January 2005–September 2010)

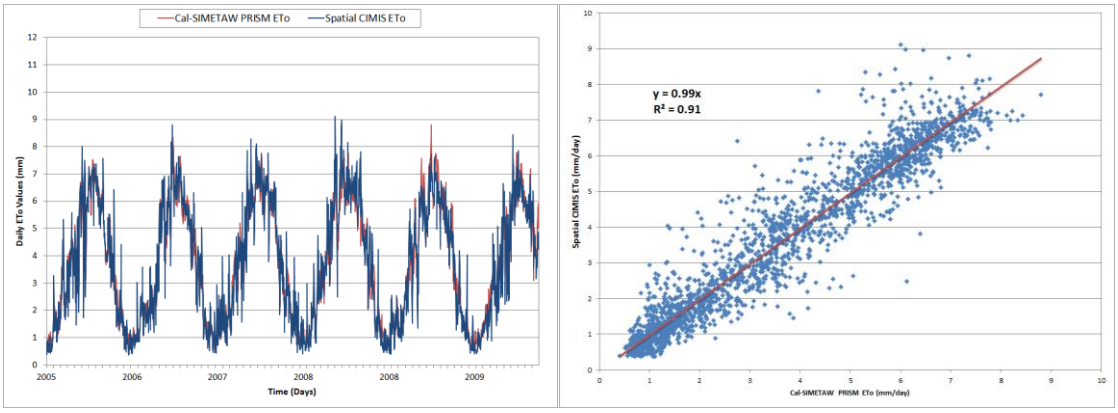


Figure B29. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 166/Sutter County (January 2005–September 2010)

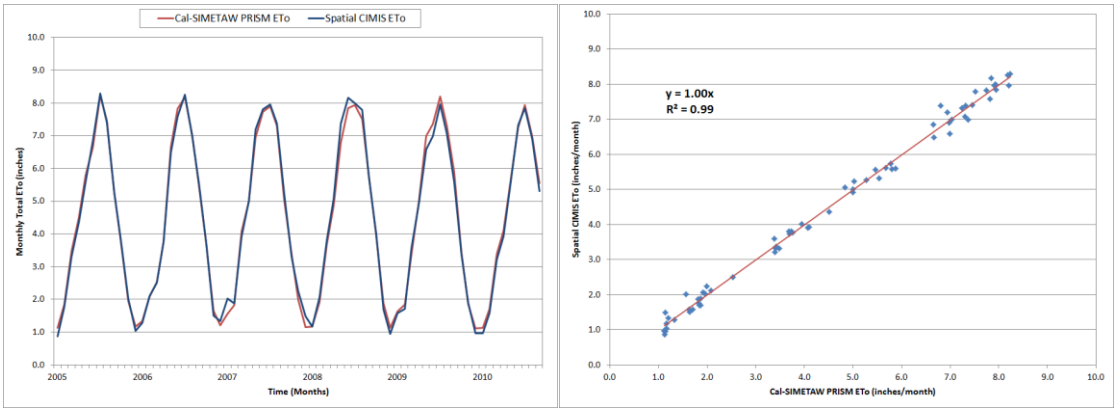
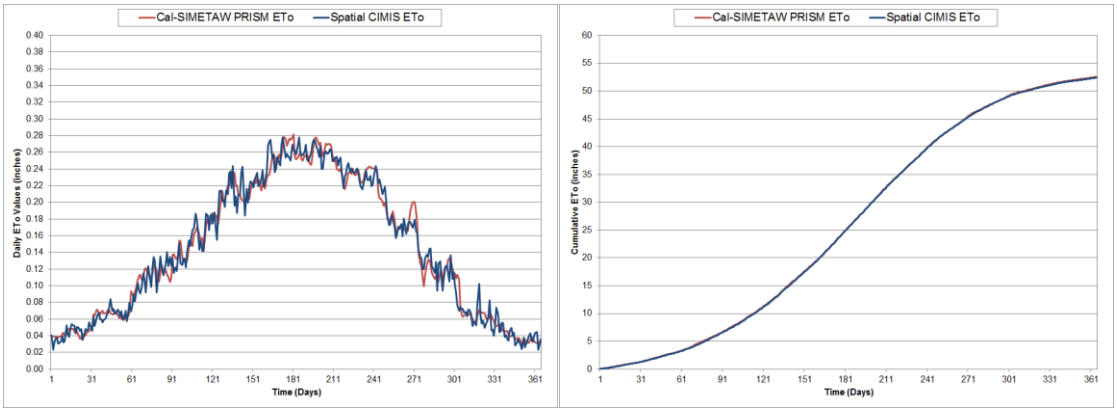


Figure B30. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 166/Sutter County (January 2005–September 2010)



Notes:
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Figure B31. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 167/Colusa County (January 2005–September 2010)

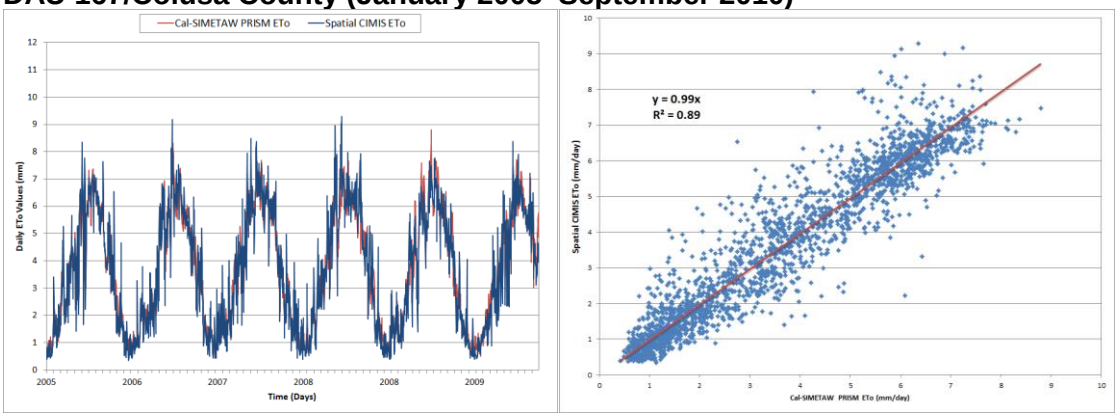


Figure B32. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 167/Colusa County (January 2005–September 2010)

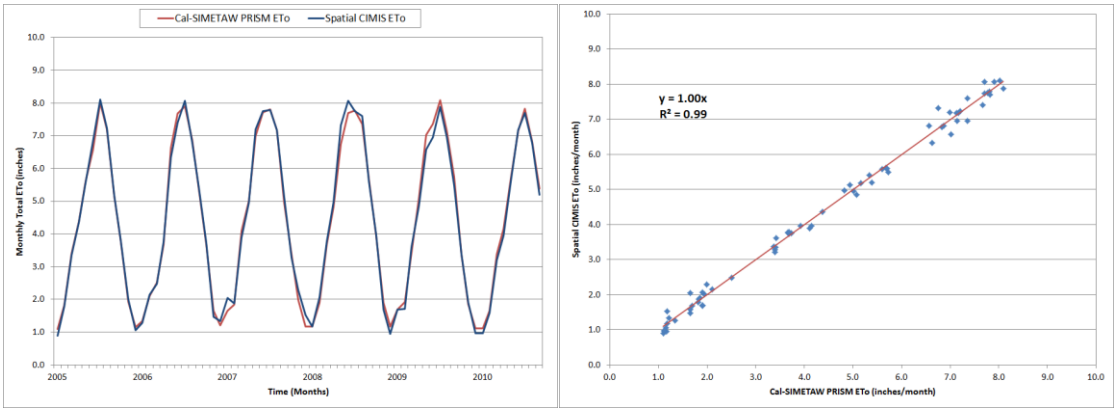
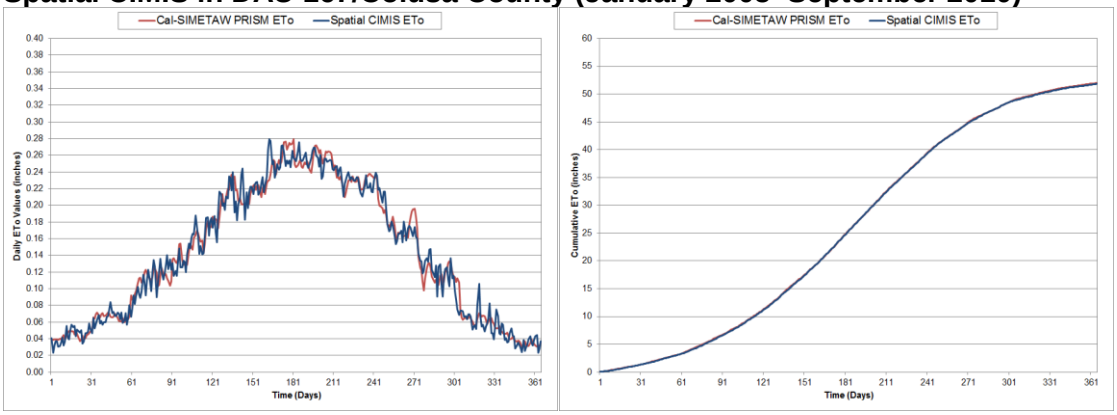


Figure B33. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 167/Colusa County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B34. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 167/Glenn County (January 2005–September 2010)

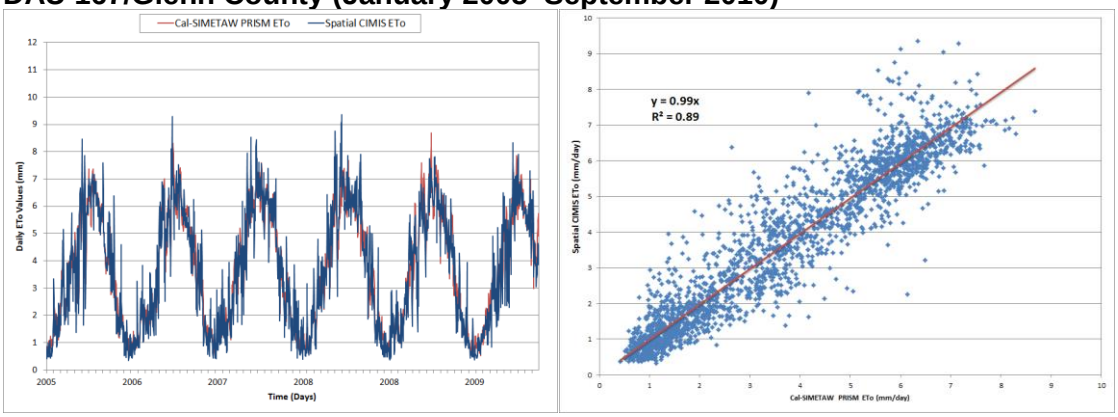


Figure B35. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 167/Glenn County (January 2005–September 2010)

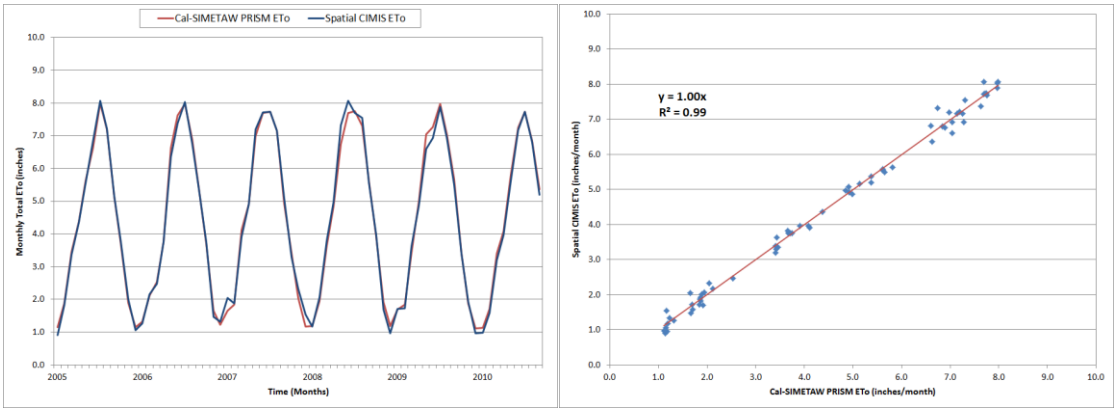
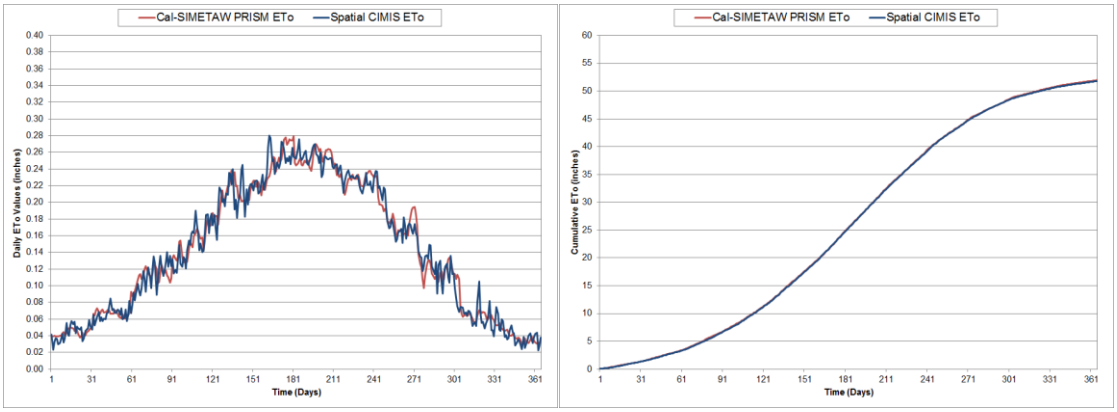


Figure B36. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 167/Glenn County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B37. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 167/Butte County (January 2005–September 2010)

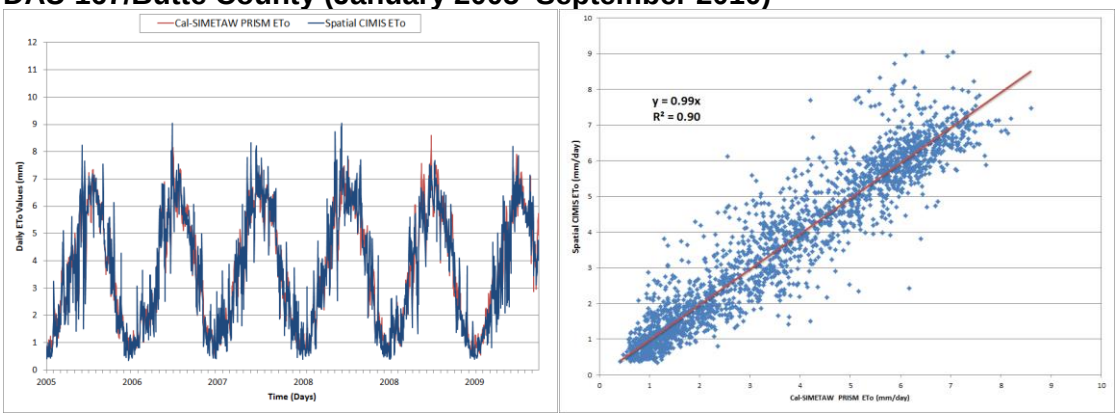


Figure B38. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 167/Butte County (January 2005–September 2010)

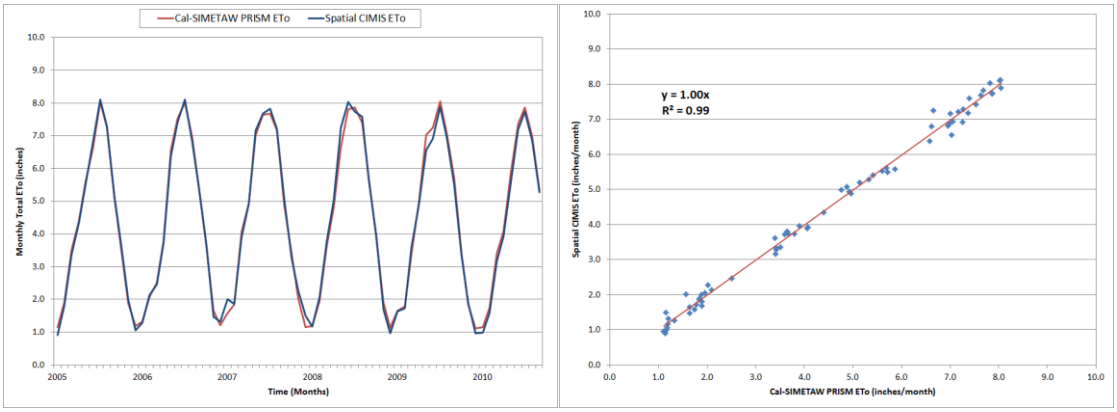
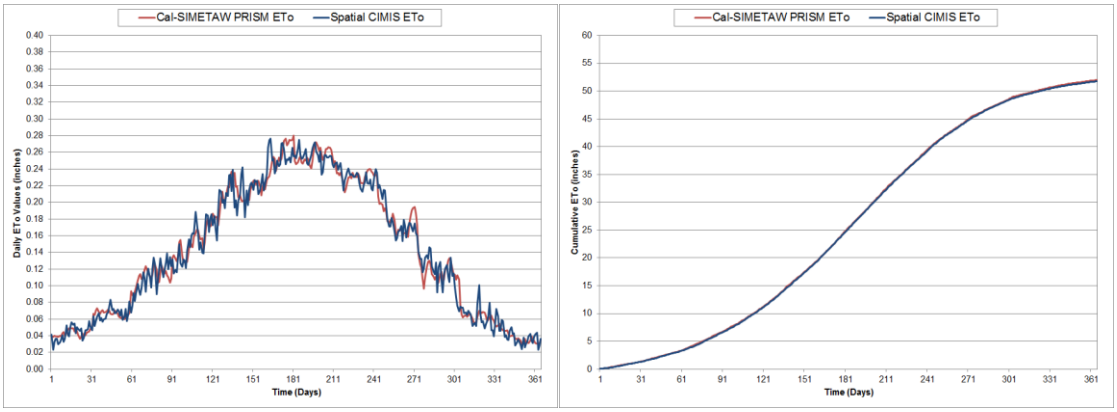


Figure B39. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 167/Butte County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B40. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 168/Sutter County (January 2005–September 2010)

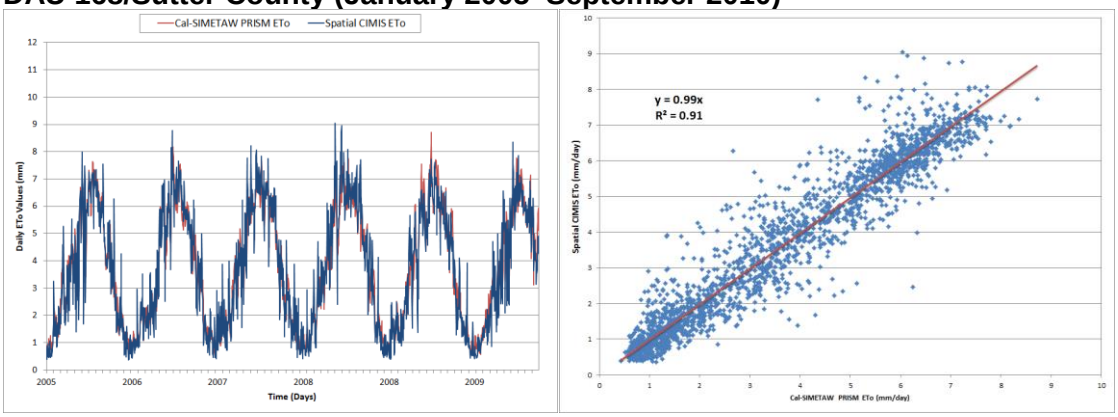


Figure B41. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 168/Sutter County (January 2005–September 2010)

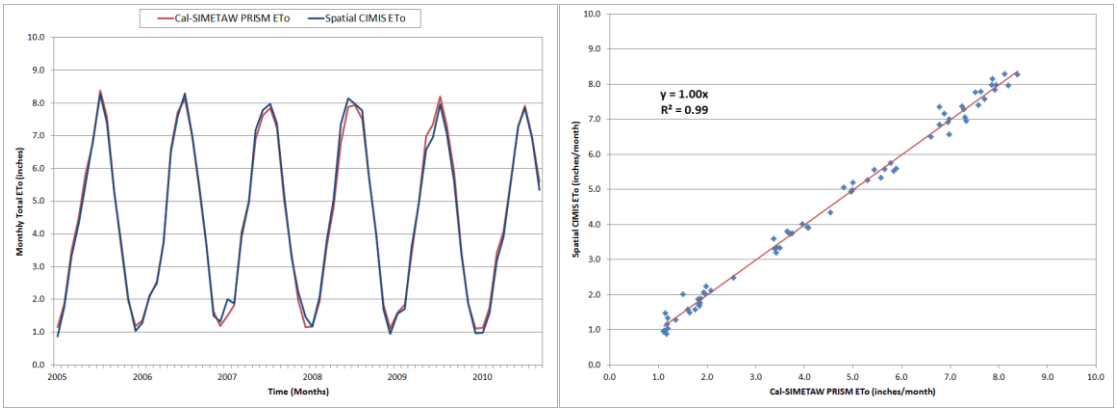
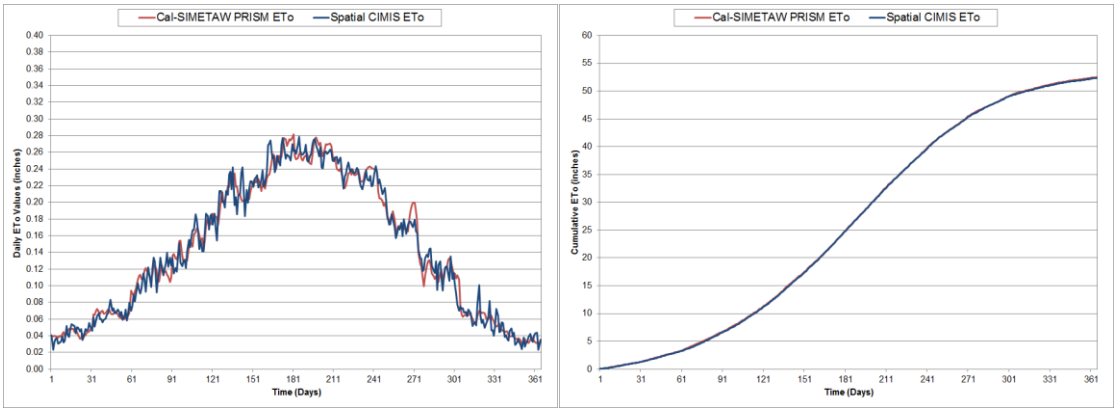


Figure B42. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 168/Sutter County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B43. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 171/Yuba County (January 2005–September 2010)

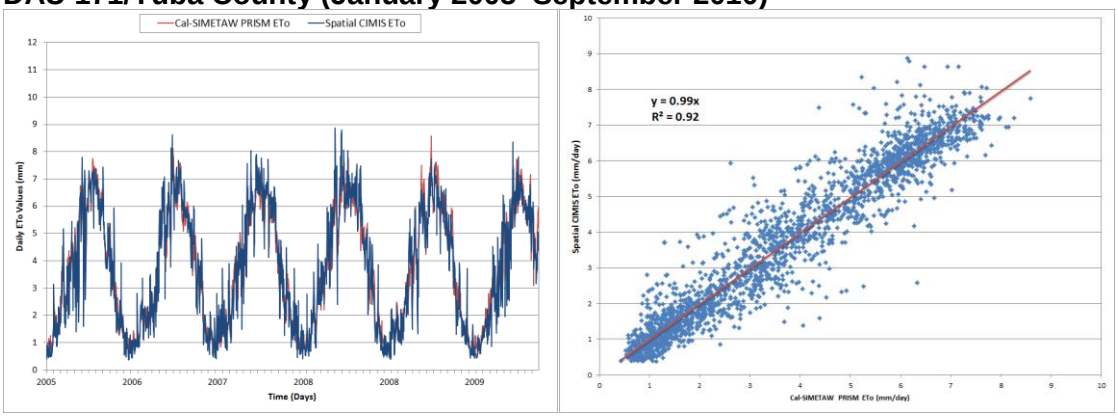


Figure B44. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 171/Yuba County (January 2005–September 2010)

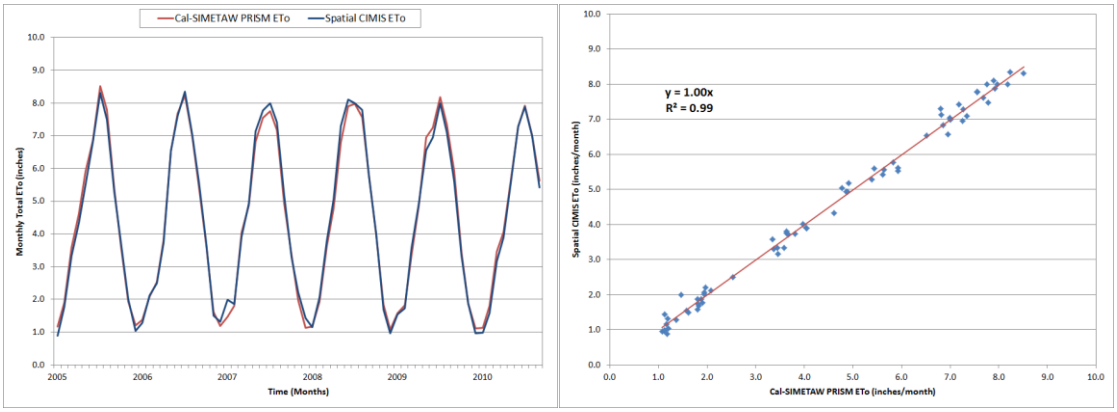
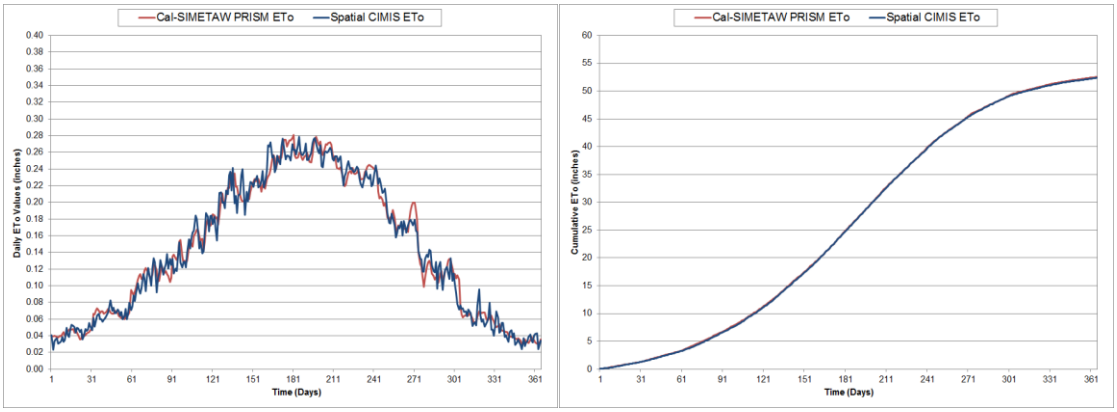


Figure B45. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 171/Yuba County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B46. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 172/Placer County (January 2005–September 2010)

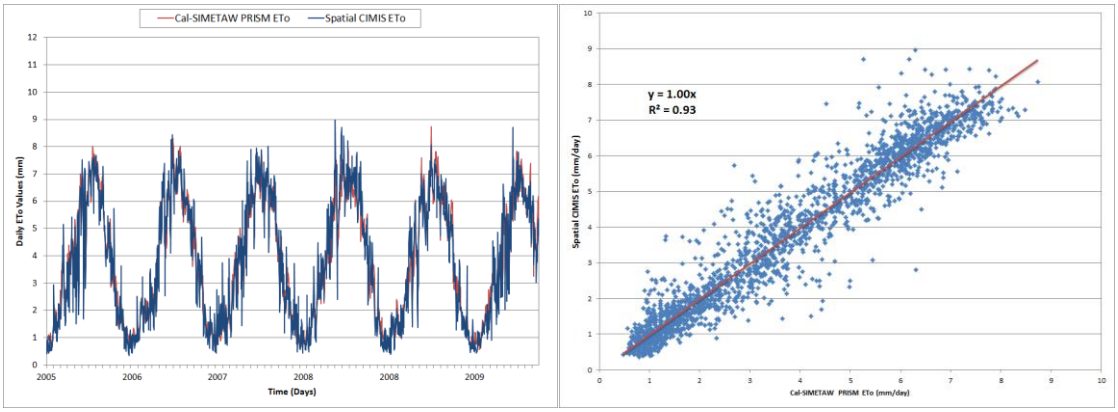


Figure B47. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 172/Placer County (January 2005–September 2010)

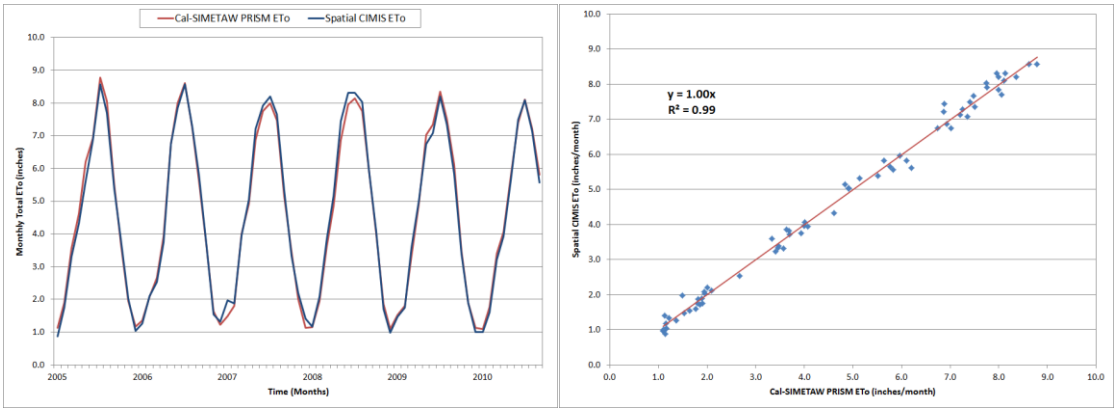
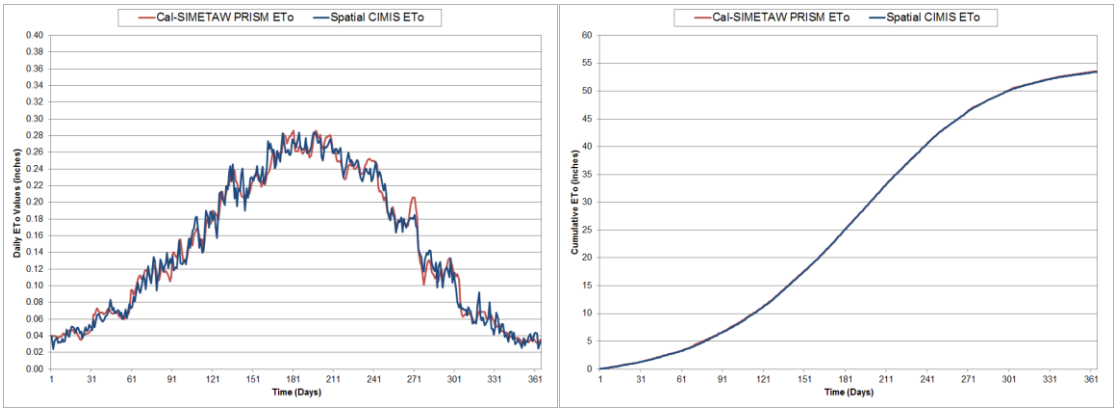


Figure B48. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 172/Placer County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B49. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 172/Sacramento County (January 2005 to September 2010)

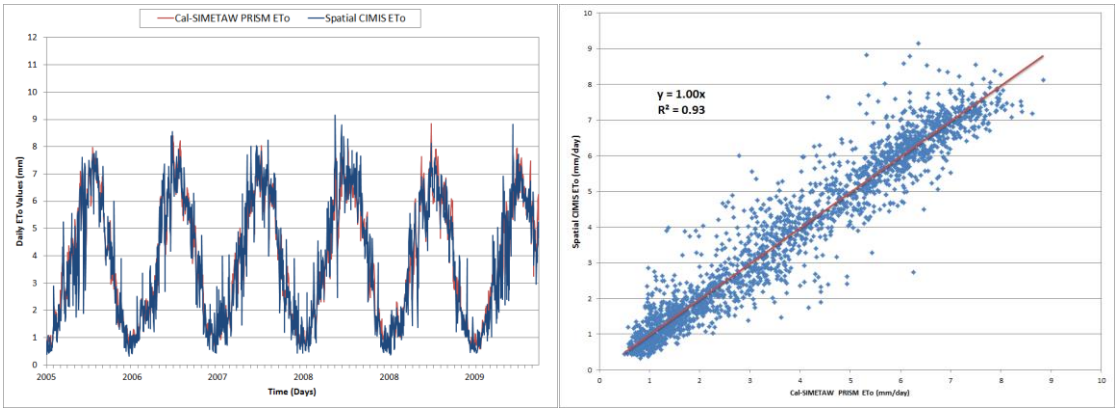


Figure B50. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 172/Sacramento County (January 2005 to September 2010)

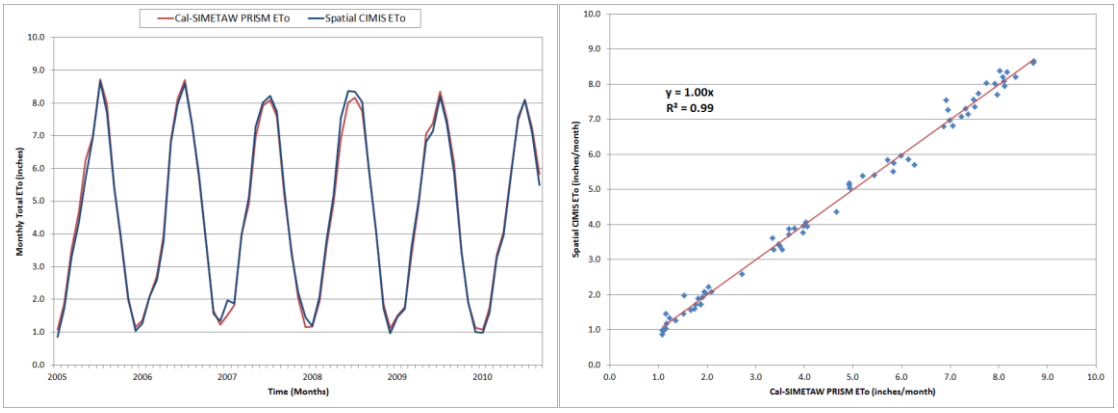
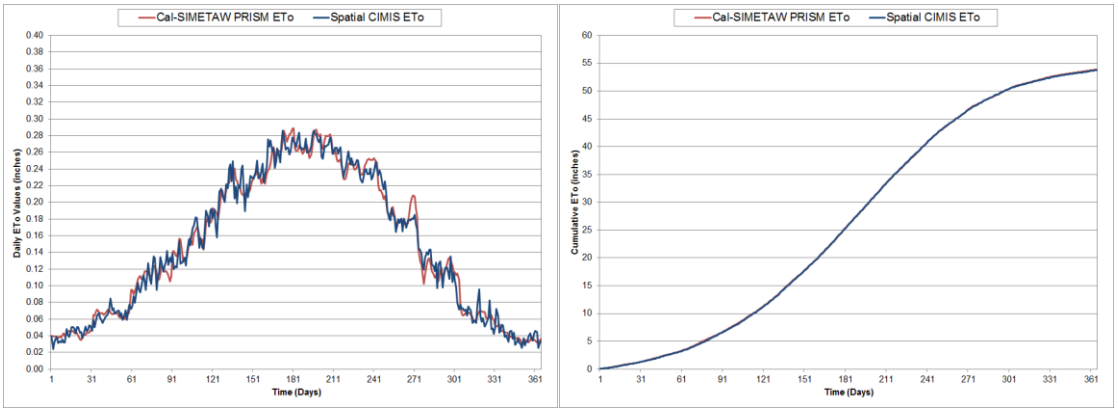


Figure B51. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 172/Sacramento County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B52. Daily Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 172/Sutter County (January 2005–September 2010)

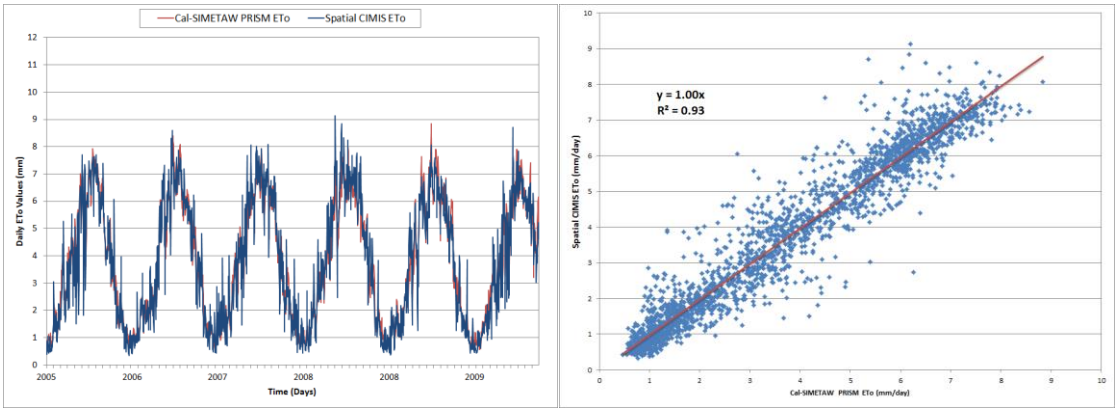


Figure B53. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 172/Sutter County (January 2005–September 2010)

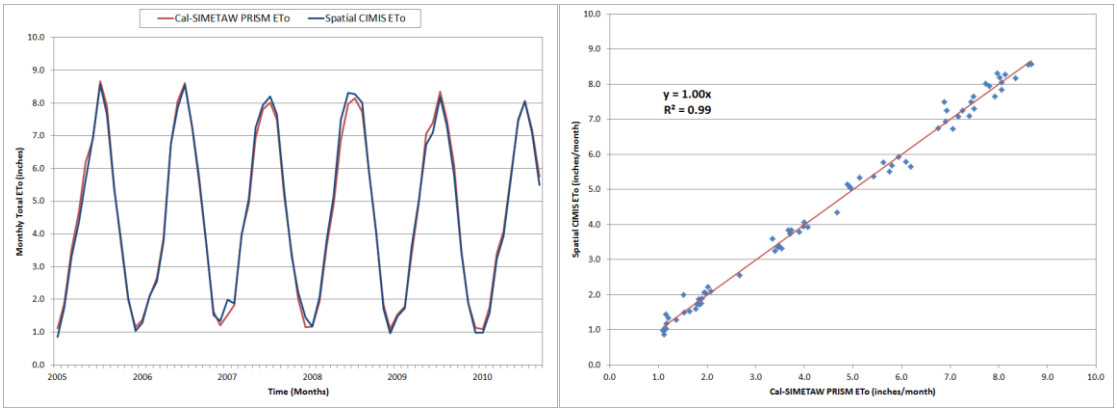
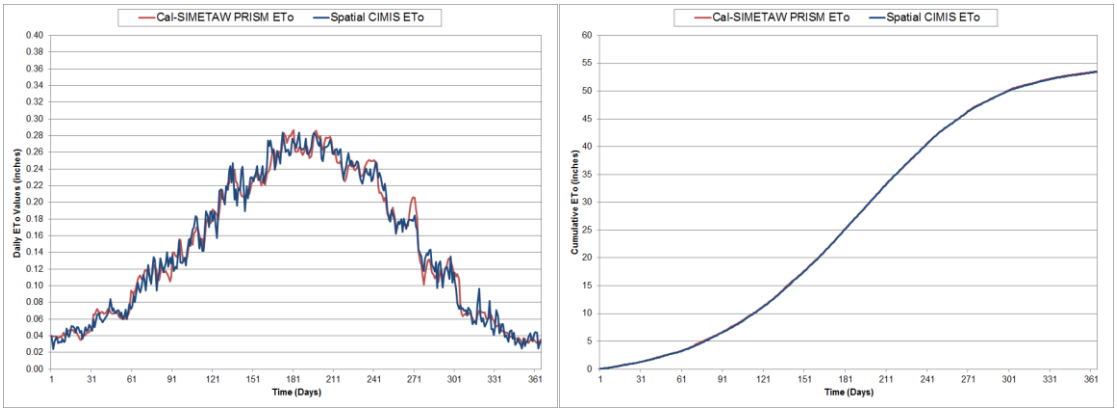


Figure B54. Daily Estimated Weighted Mean ETo and Cumulative Eto for PRISM and Spatial CIMIS in DAU 172/Sutter County (January 2005–September 2010)



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, Eto = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Figure B55. Daily Weighted Mean Eto Estimates for PRISM and Spatial CIMIS in DAU 186/Yolo County (January 2005–September 2010)

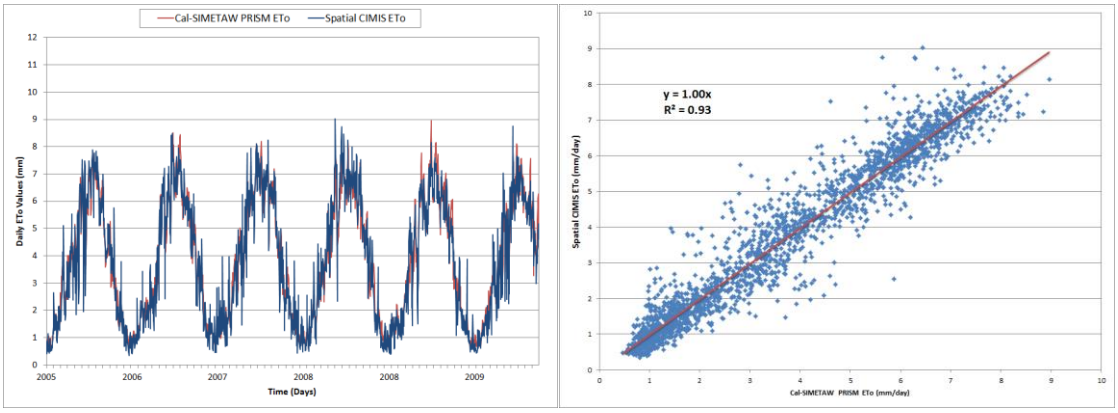


Figure B56. Monthly Weighted Mean ETo Estimates for PRISM and Spatial CIMIS in DAU 186/Yolo County (January 2005–September 2010)

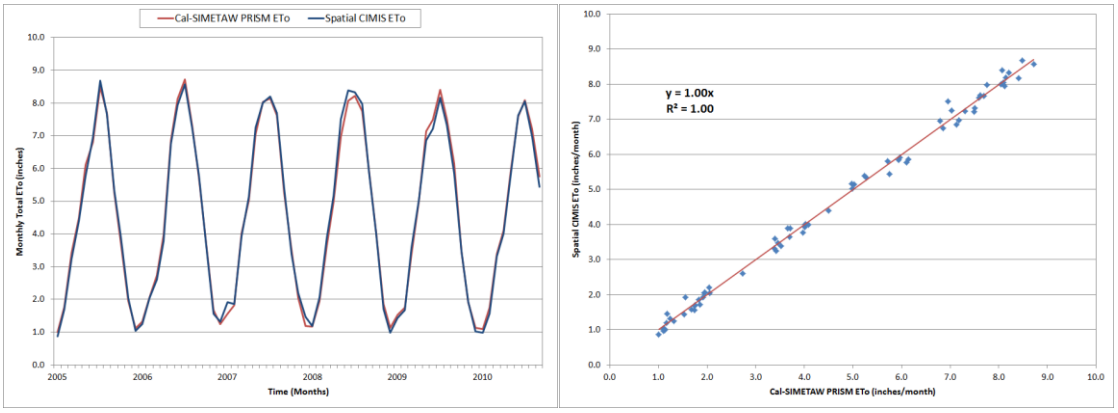
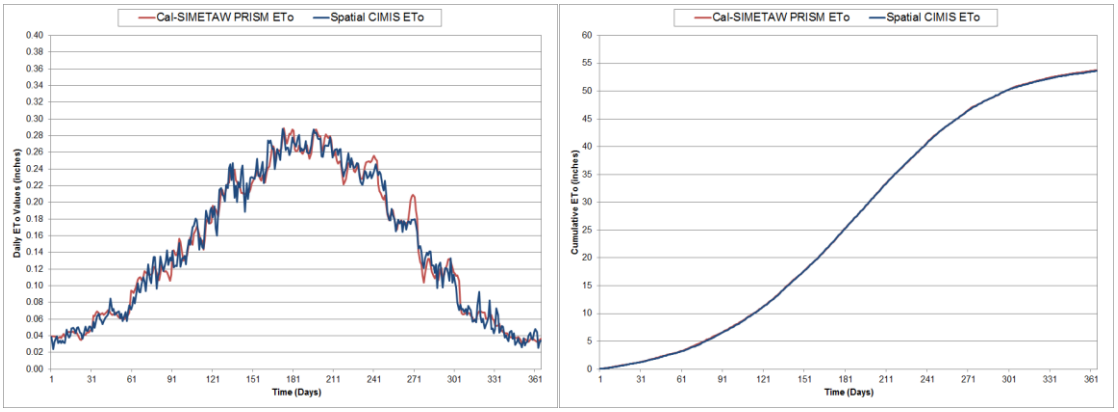


Figure B57. Daily Estimated Weighted Mean ETo and Cumulative ETo for PRISM and Spatial CIMIS in DAU 186/Yolo County (January 2005–September 2010)

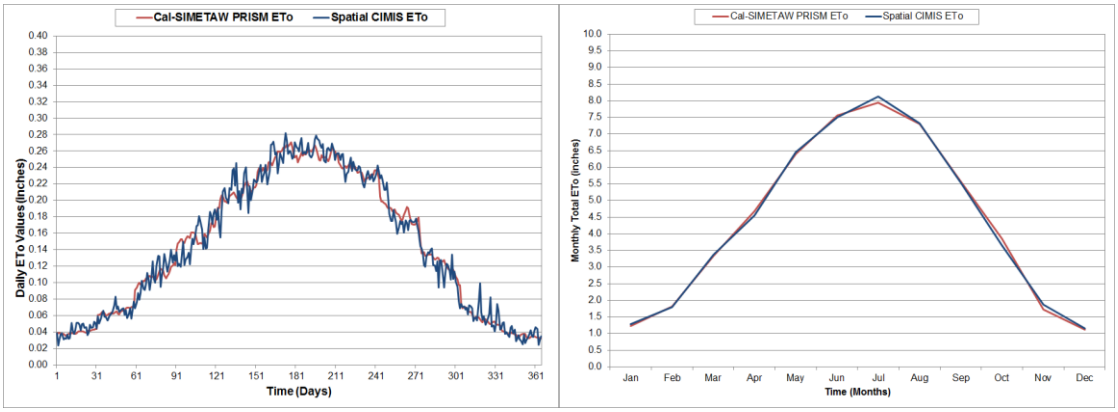


Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, PRISM = Parameter elevation Regression on Independent Slopes

Appendix C: Verification of Reference Evapotranspiration Correction Factors at Detailed Analysis Unit/County Level

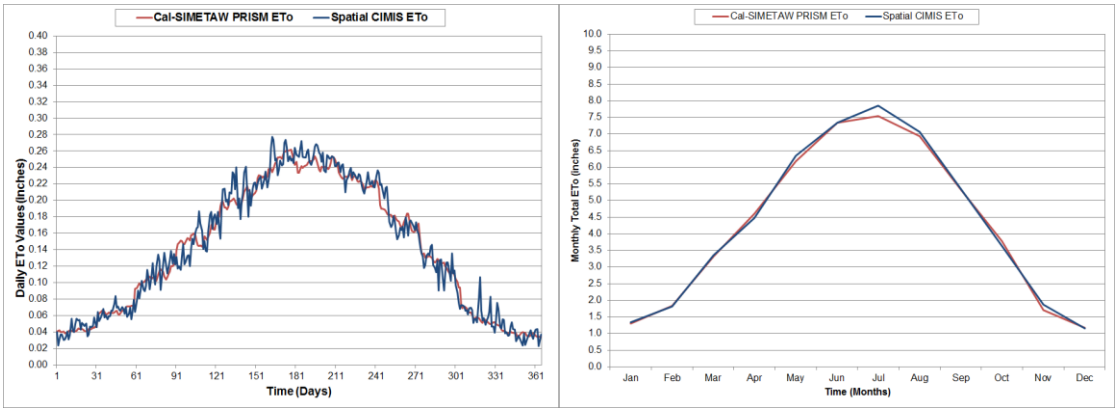
The plots in Appendix C illustrate that daily and monthly estimated weighted-mean ETo from a calibrated HS equation during the 1981–2004 period, were well correlated with the Spatial CIMIS during a five-year period, 2005–2010, on each of the 19 DAU/counties within the Sacramento Valley region.

Figure C1. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 162/Yolo County



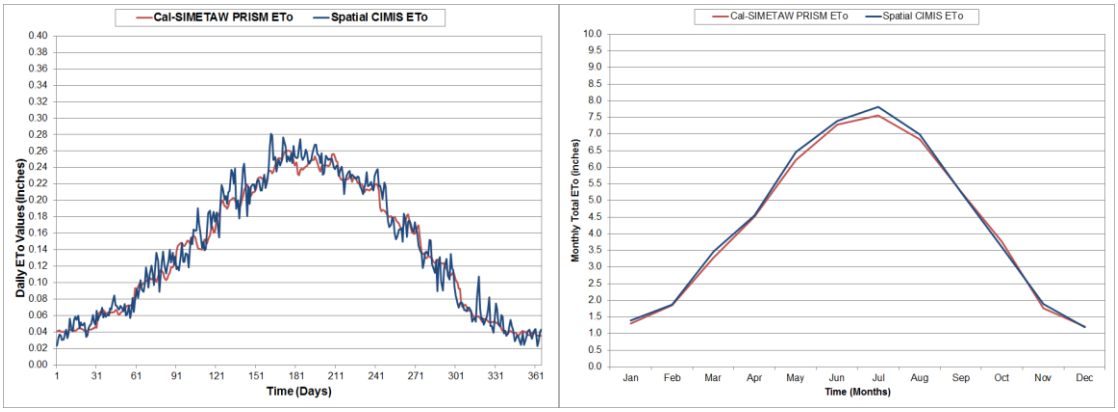
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C2. Daily and Monthly Estimated Weighted Mean Eto from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 163/Colusa County



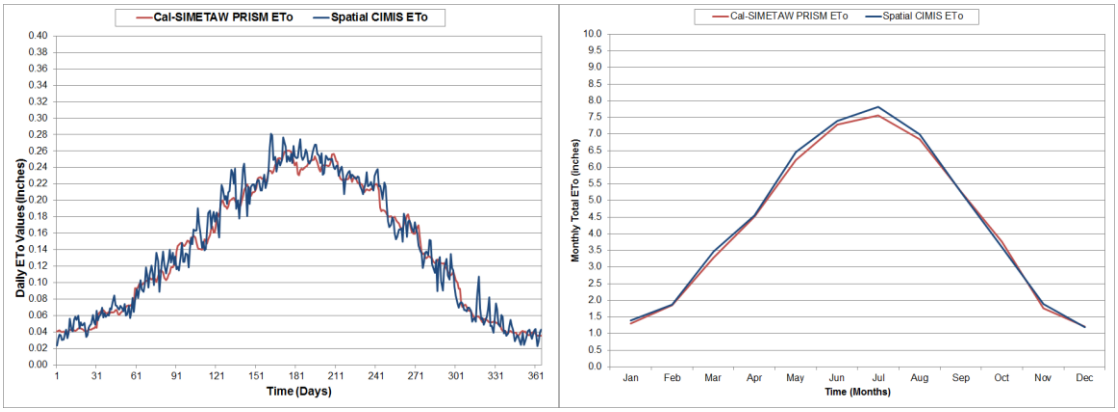
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C3. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 163/Glenn County



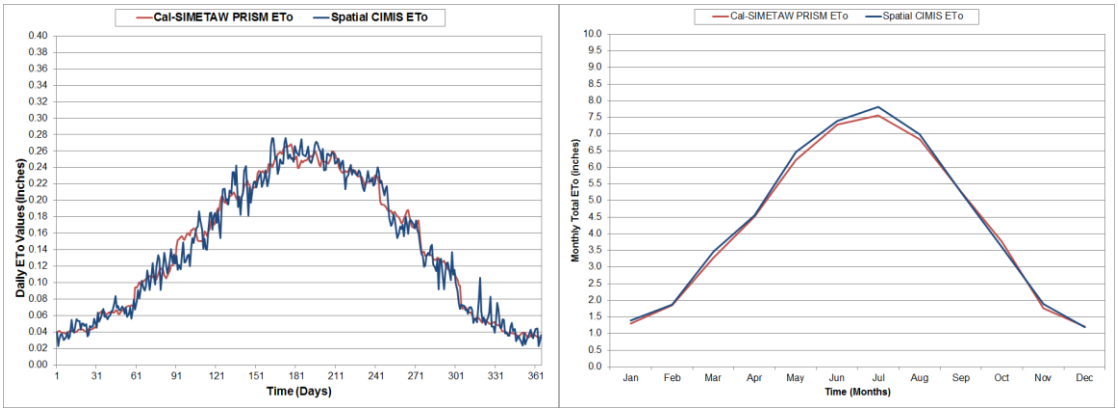
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C4. Dily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 163/Yolo County



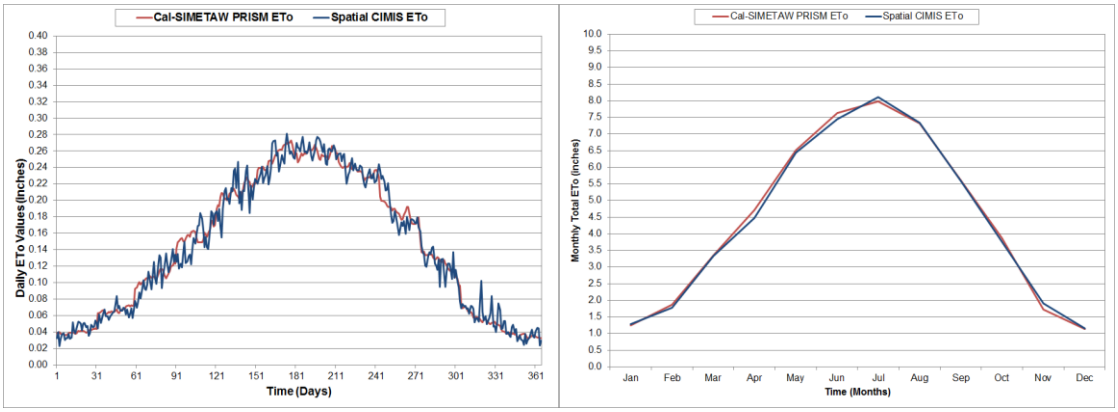
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C5. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 164/Colusa County



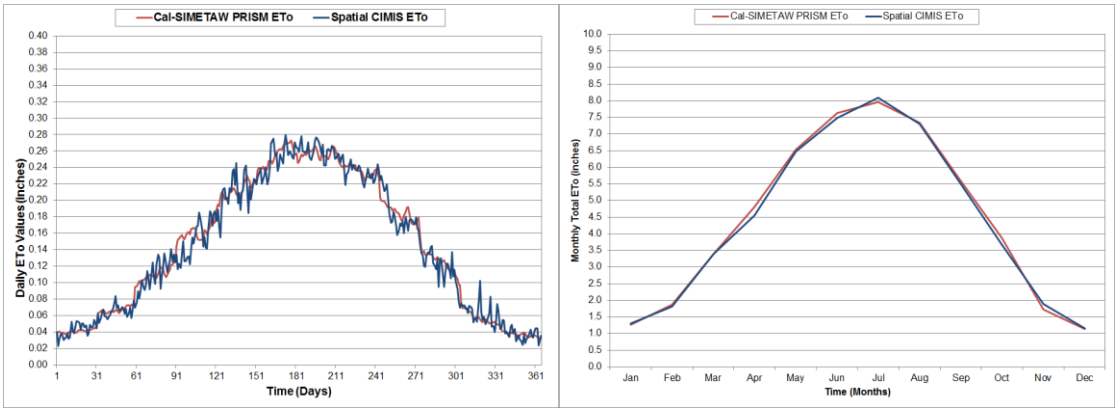
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C6. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 164/Colusa County



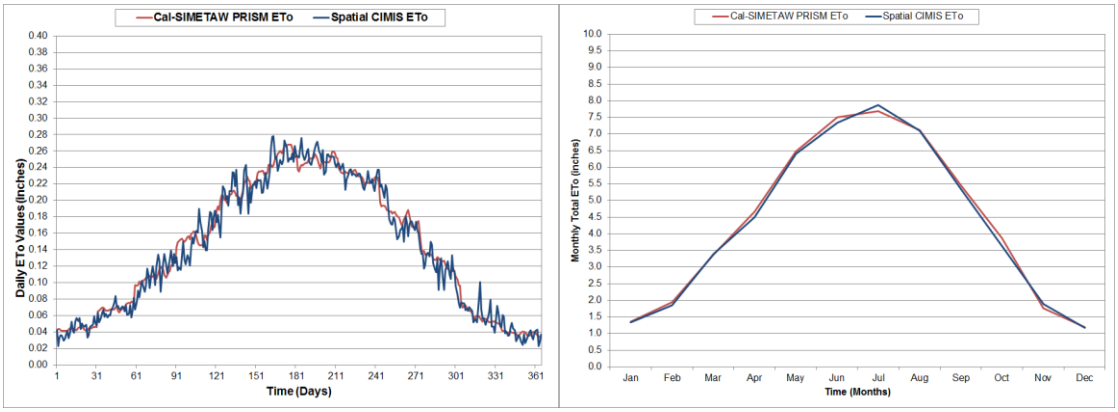
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C7. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 165/Sutter County



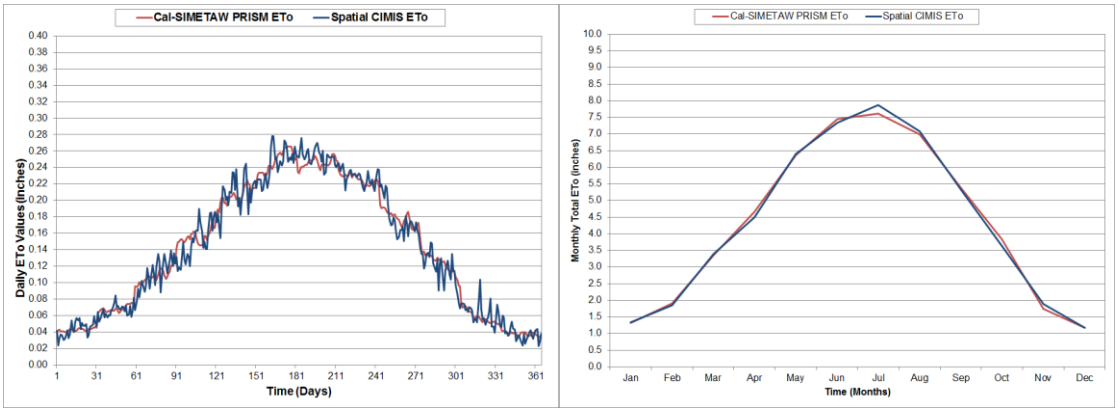
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C8. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 166/Butte County



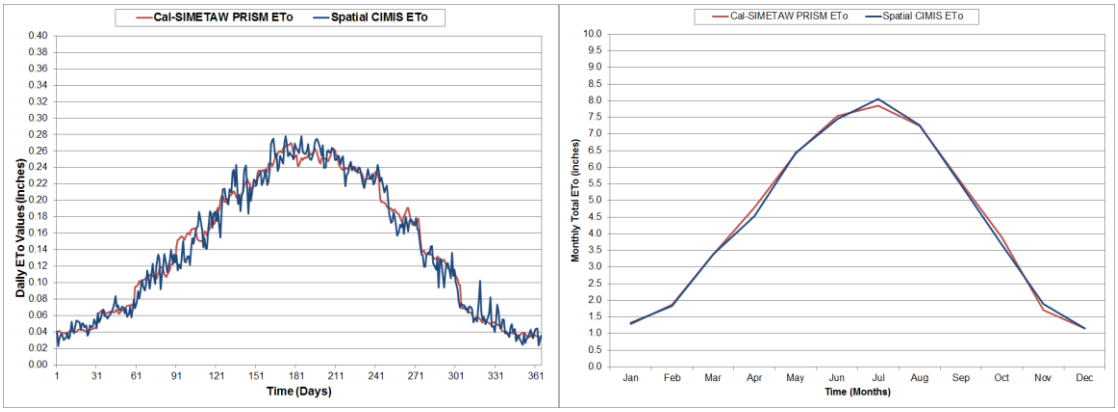
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C9. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 166/Glenn County



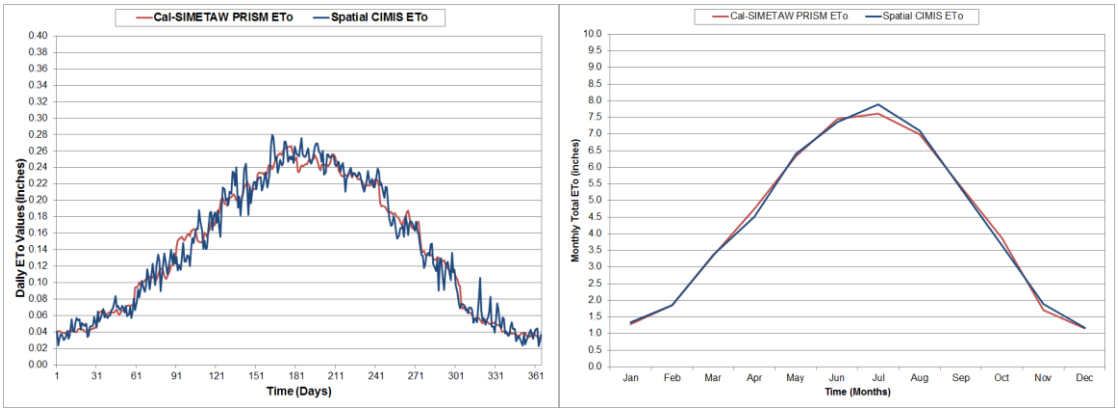
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C10. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 166/Sutter County



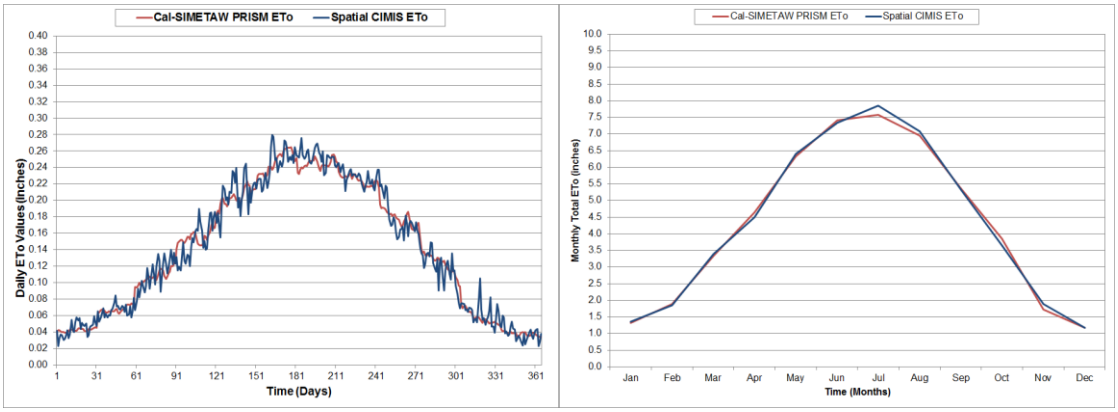
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C11. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 167/Colusa County



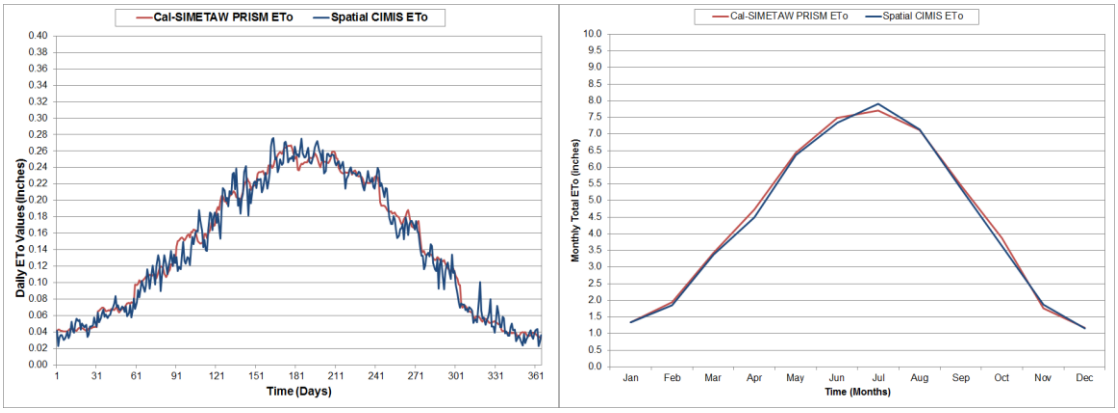
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C12. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 167/Glenn County



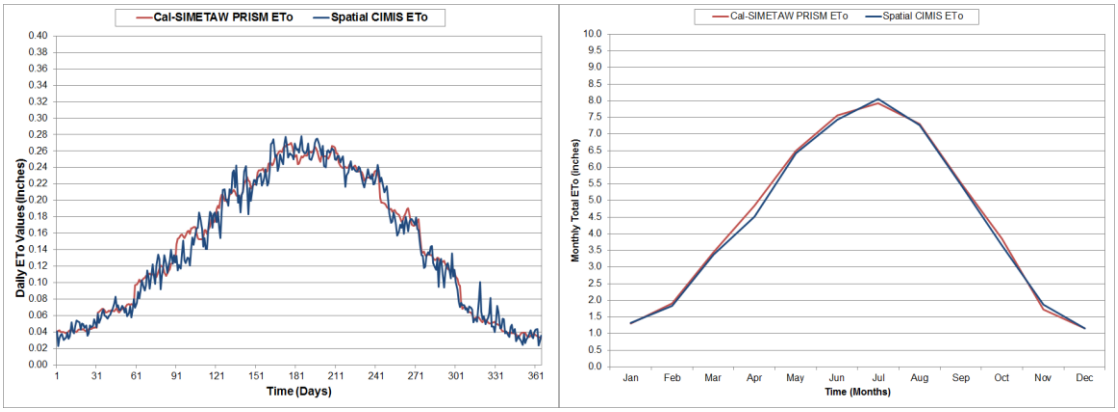
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C13. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 168/Butte County



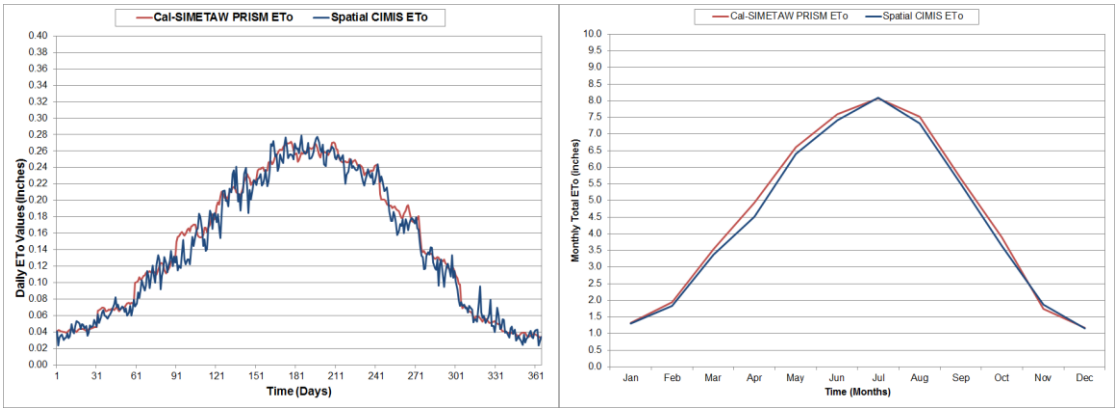
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C14. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 168/Sutter County



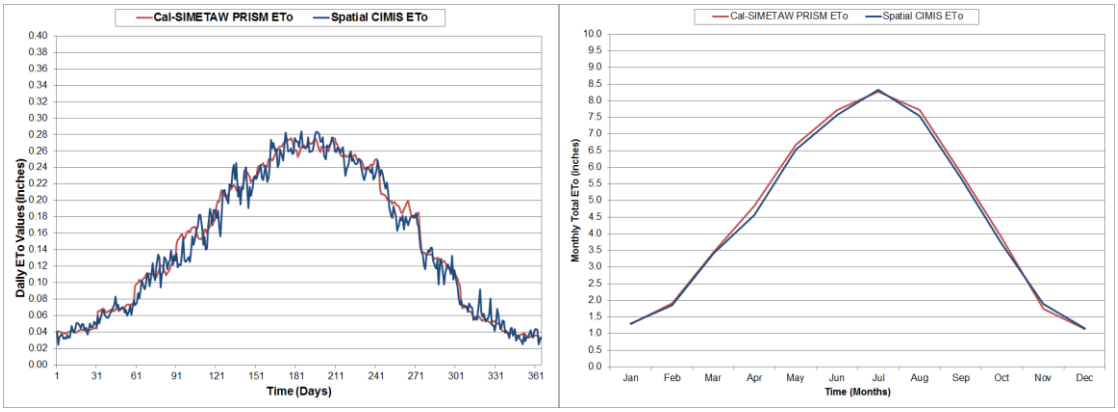
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C15. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 171/Yuba County



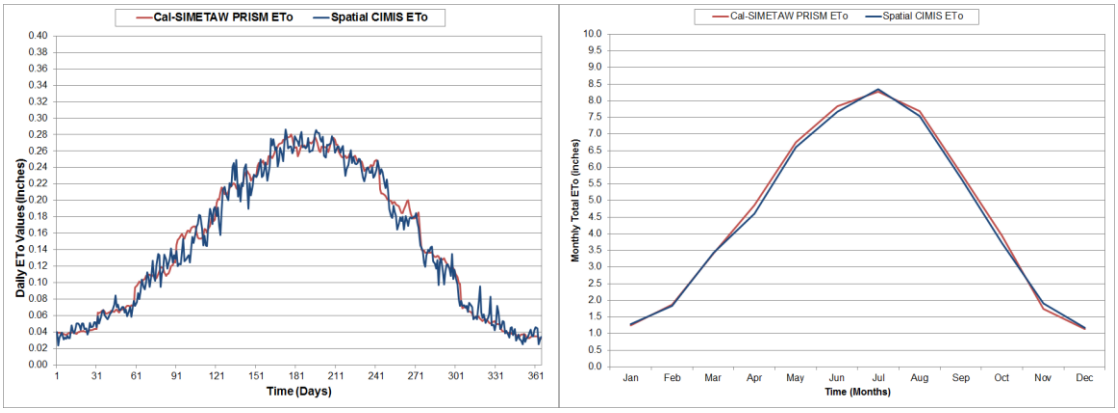
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C16. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 172/Placer County



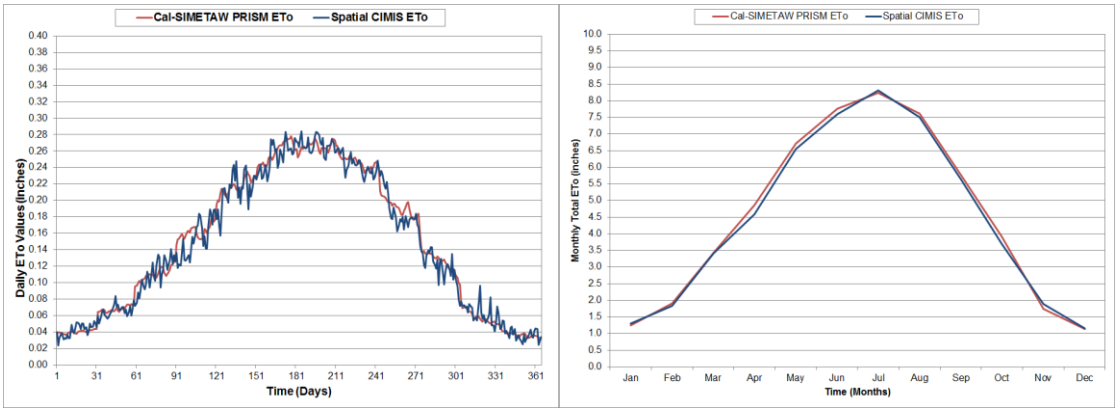
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C17. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 172/Sacramento County



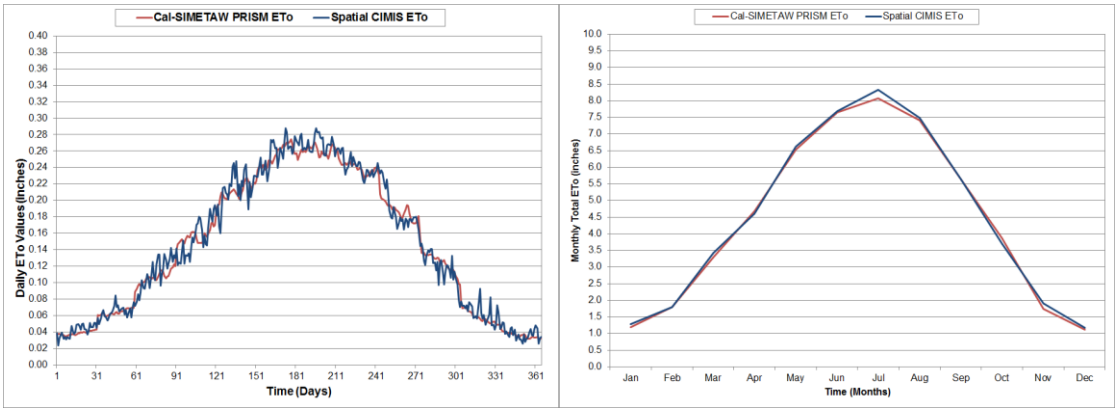
Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Figure C18. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 172/Sutter County



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

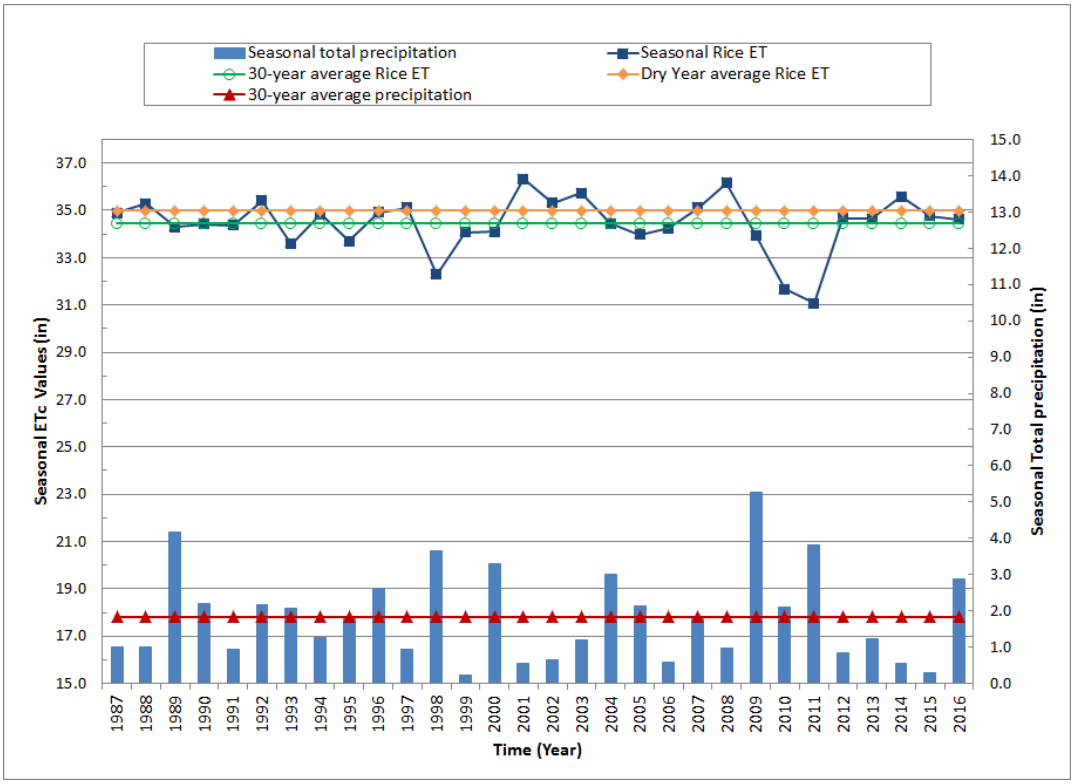
Figure C19. Daily and Monthly Estimated Weighted Mean ETo from a Calibrated HS Equation (1981–2004) and Spatial CIMIS (2005–2010) in DAU 186/Yolo County



Notes:
Cal-SIMETAW = California Simulation of Evapotranspiration of Applied Water, CIMIS = California Irrigation Management Information System, DAU = detailed analysis unit, ETo = reference evapotranspiration, HS = Hargreaves-Samani

Appendix D: Comparison of Annual and 30-Year Average Estimates of Crop Evapotranspiration and Precipitation

Figure D1. DAU 162/Yolo County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)

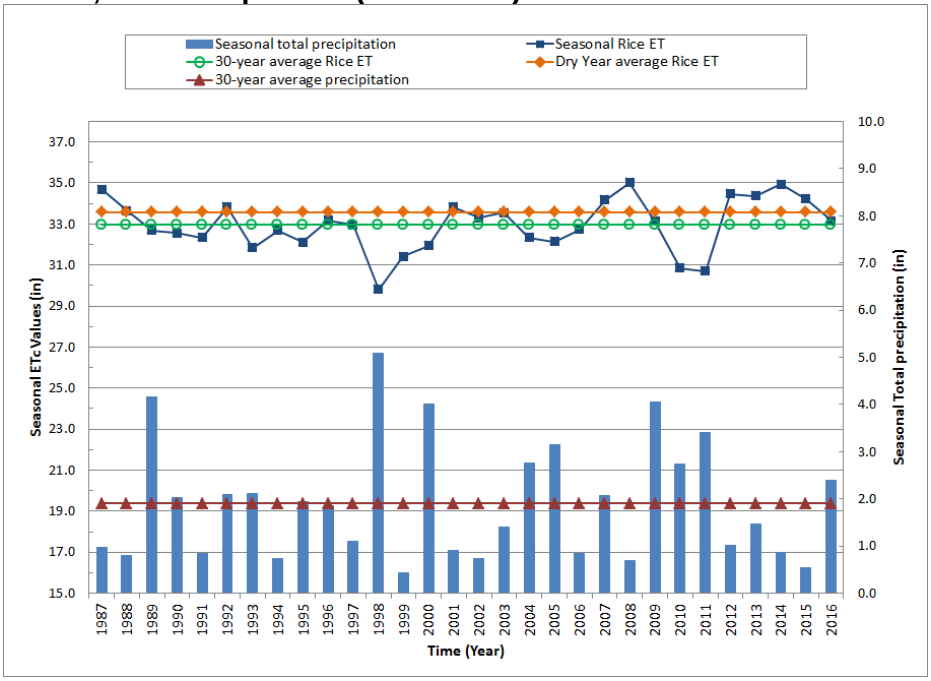


Notes:

DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration

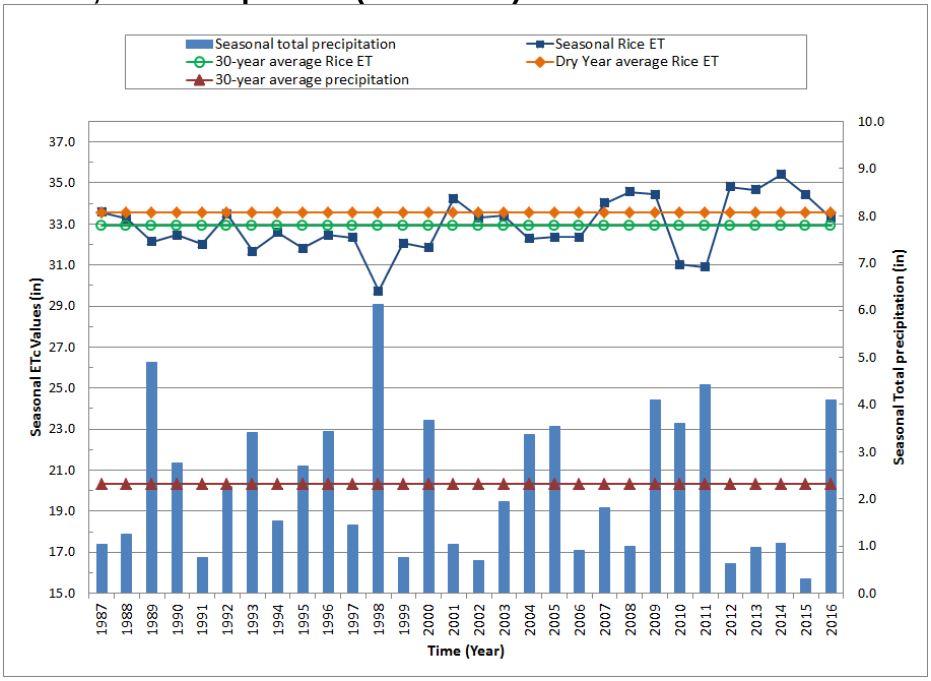
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 162/Yolo County.

Figure D2. DAU 163/Colusa County Seasonal Estimates and 30-Year averages of ETc, and Precipitation (1987–2016)



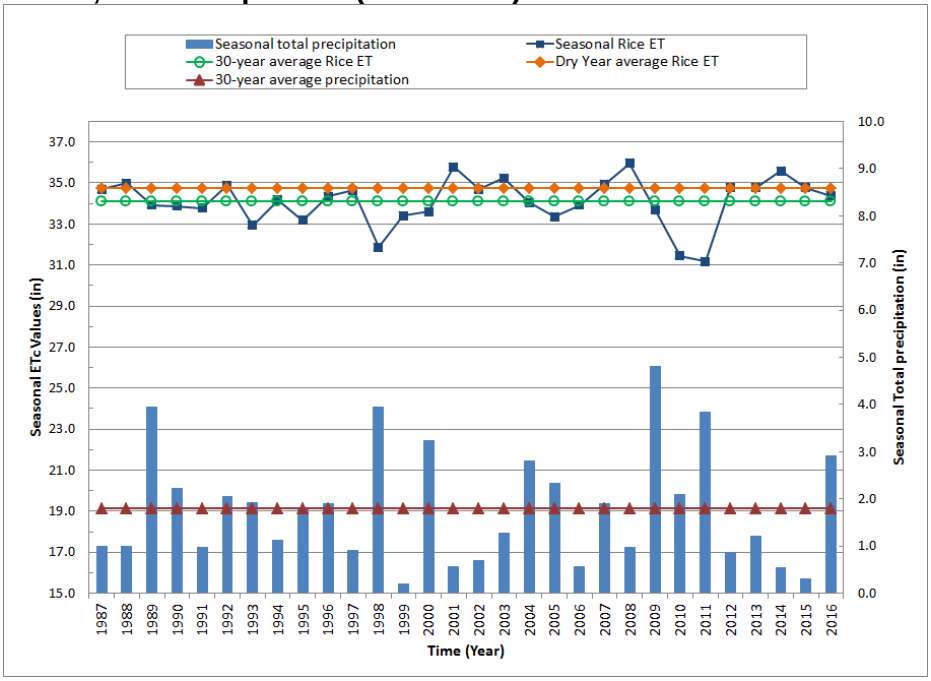
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 163/Colusa County.

Figure D3. DAU 163/Glenn County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



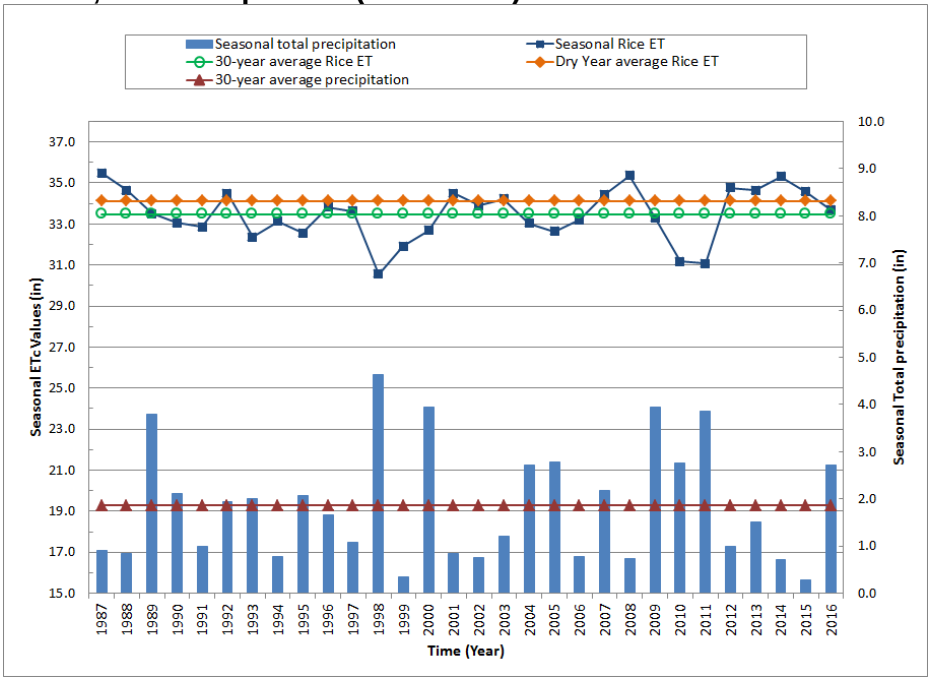
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 163/Glenn County.

Figure D4. DAU 163/Yolo County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



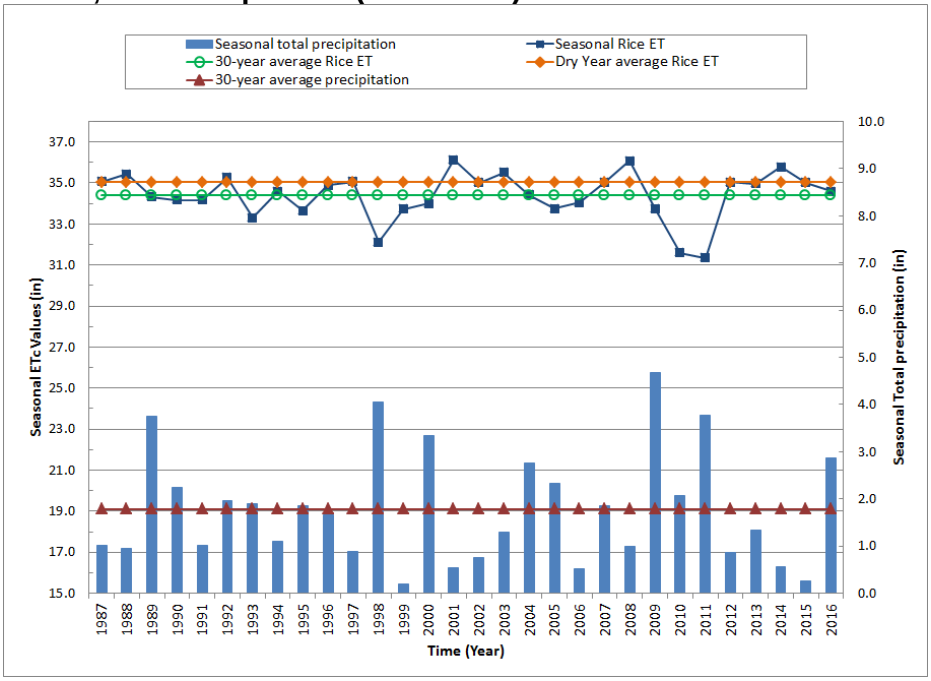
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 163/Yolo County.

Figure D5. DAU 164/Colusa County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



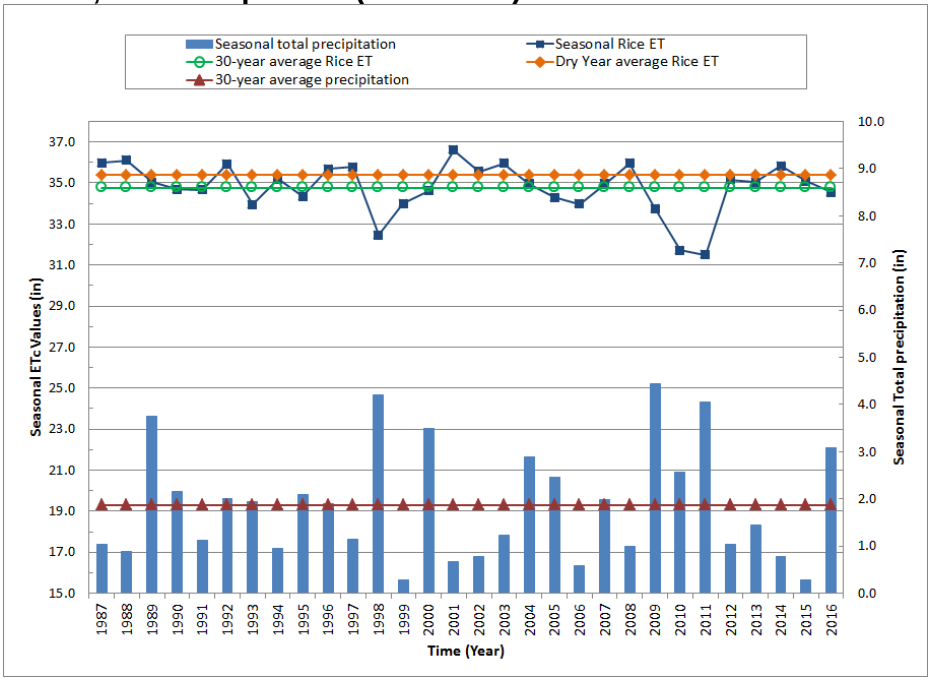
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 164/Colusa County.

Figure D6. DAU 164/Yolo County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



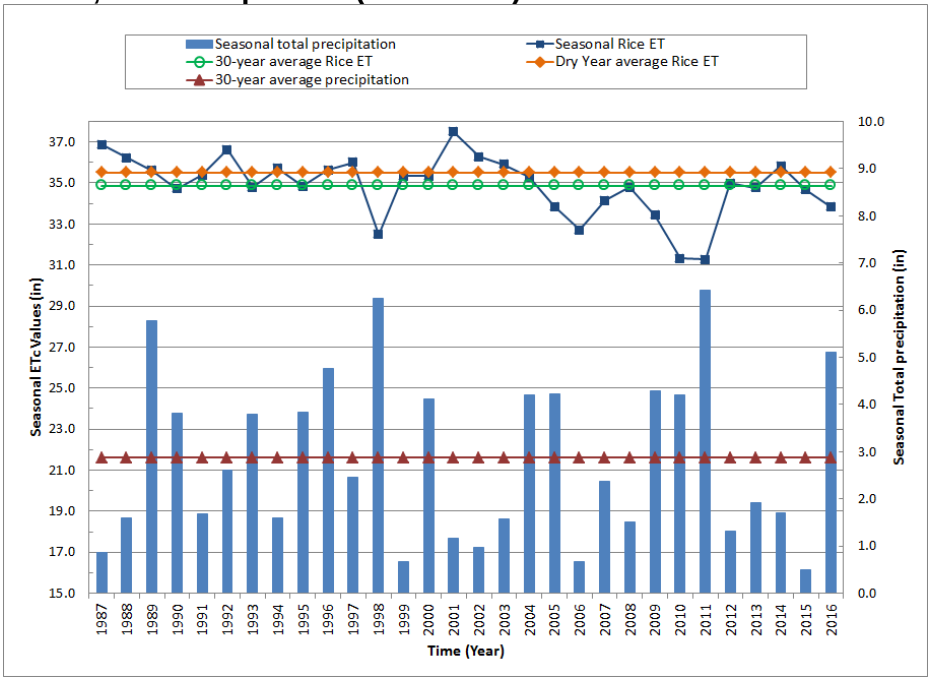
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 164/Yolo County.

Figure D7. DAU 165/Sutter County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



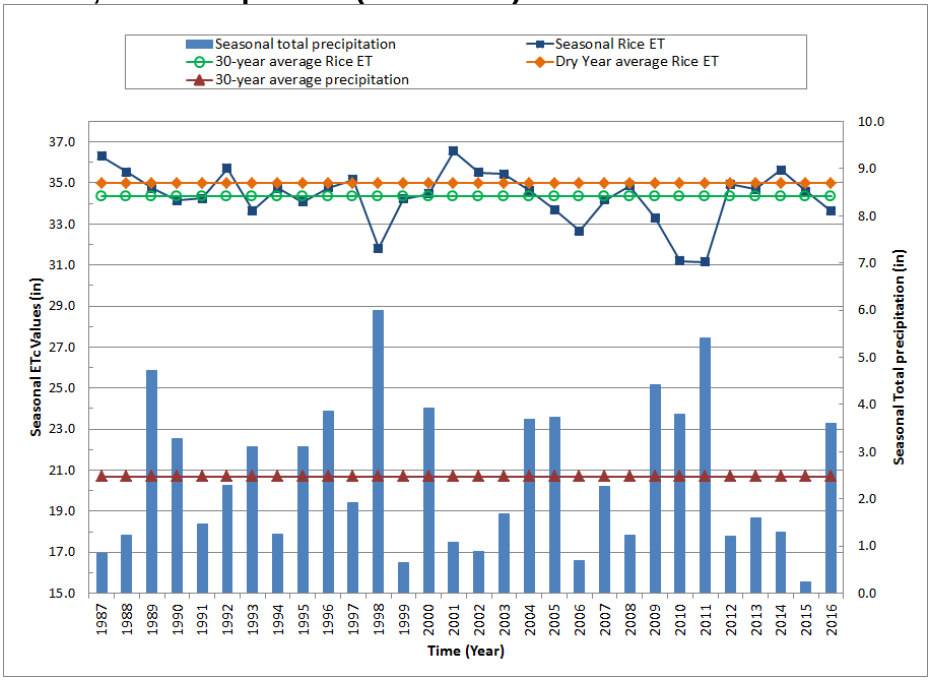
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 165/Sutter County.

Figure D8. DAU 166/Butte County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



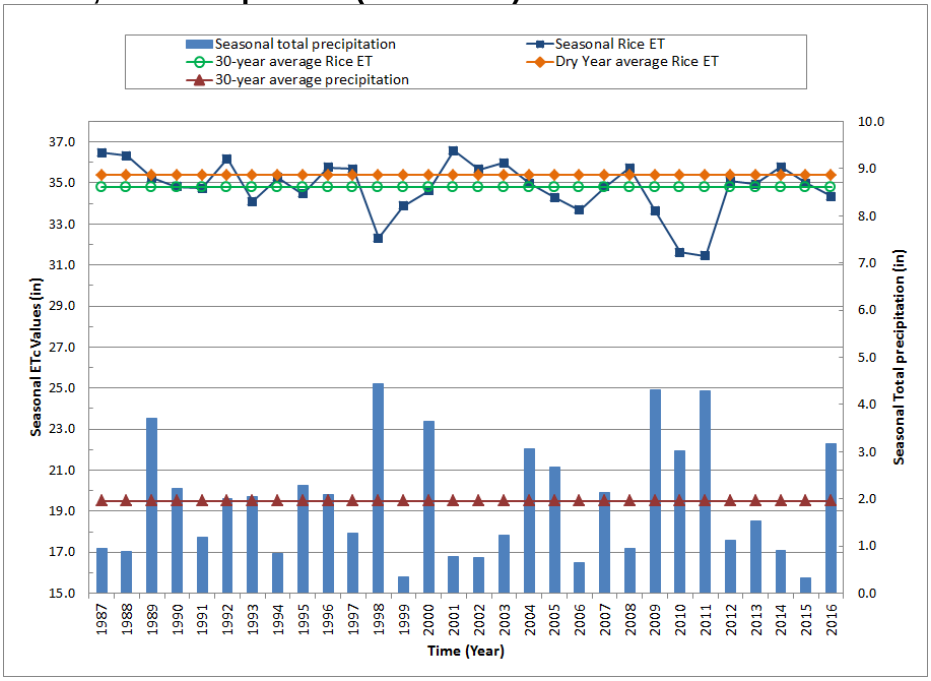
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 166/Butte County.

Figure D9. DAU 166/Glenn County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



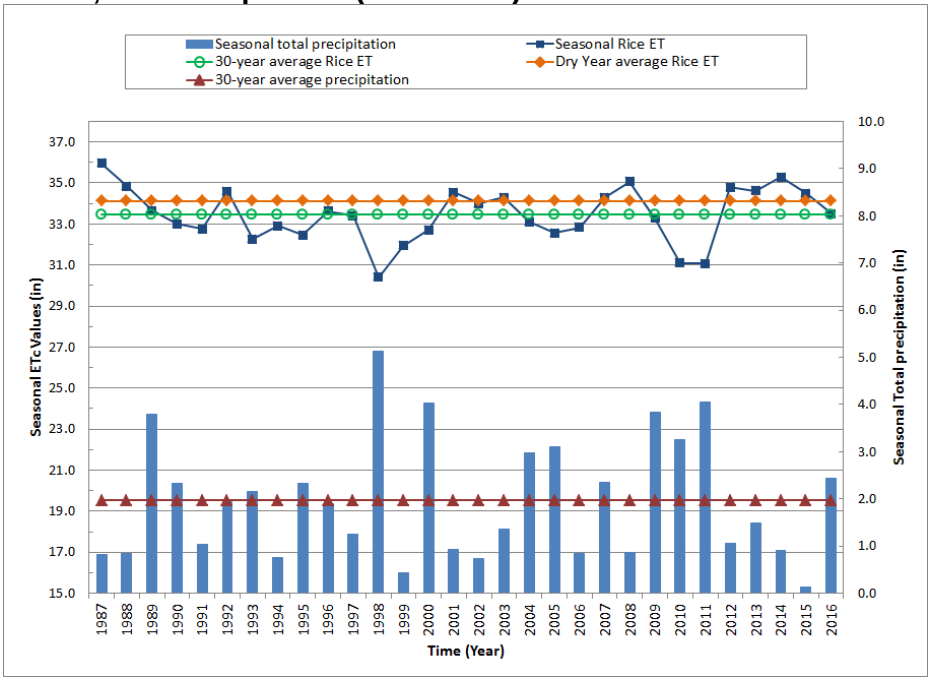
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 166/Glenn County.

Figure D10. DAU 166/Sutter County Seasonal Estimates and 30-Year averages of ETc, and Precipitation (1987–2016)



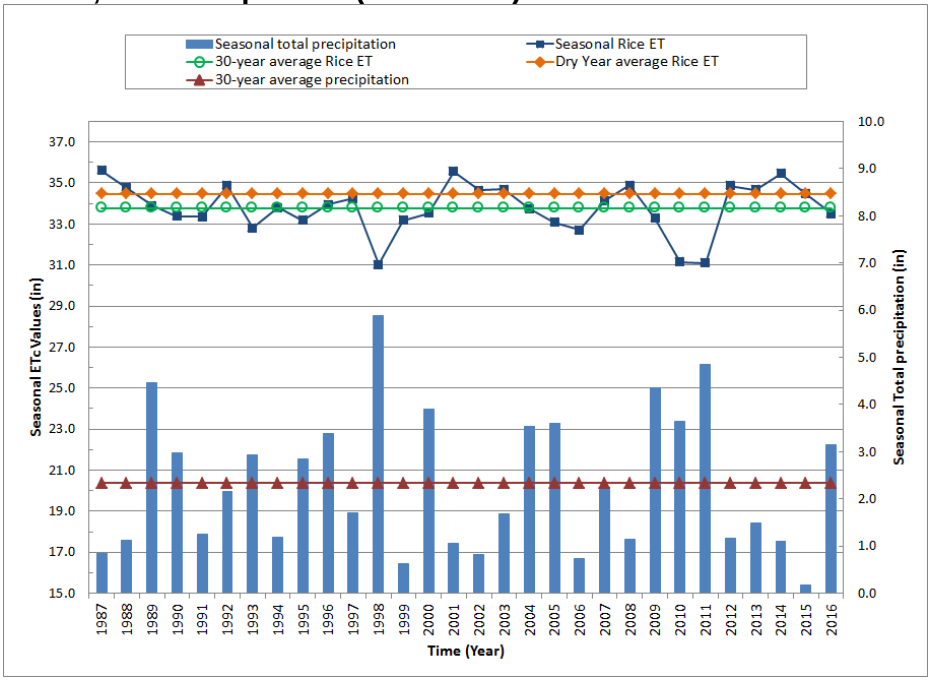
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 166/Sutter County.

Figure D11. DAU 167/Colusa County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1986–2016)



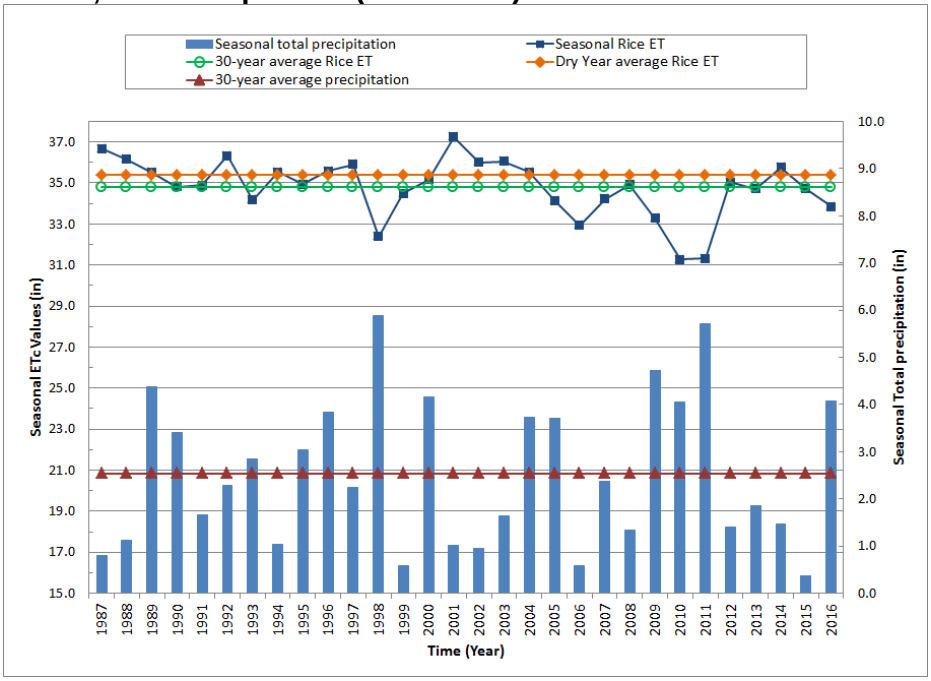
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 167/Colusa County.

Figure D12. DAU 167/Glenn County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



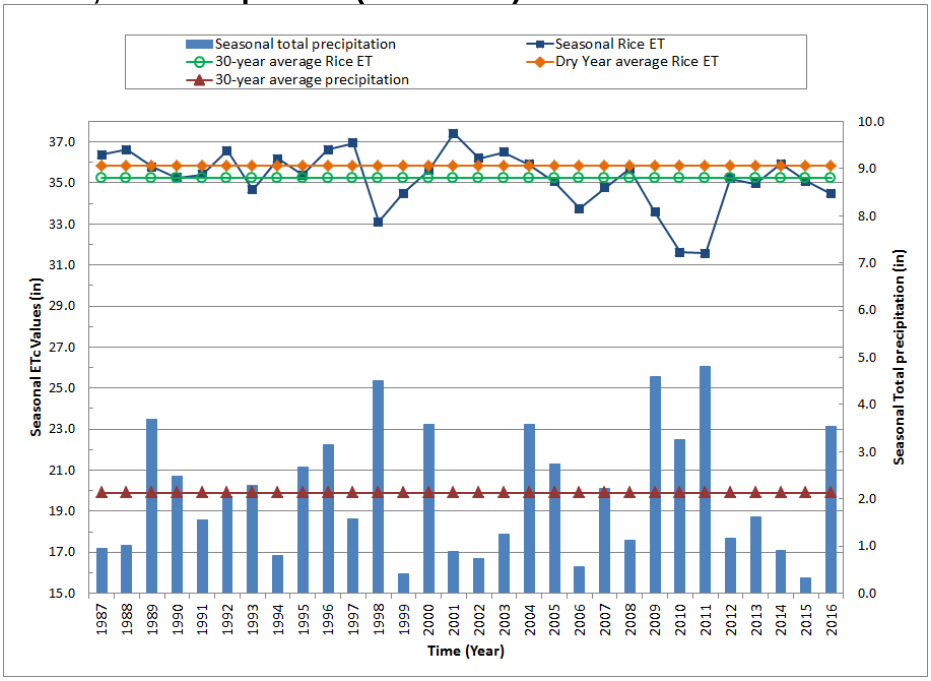
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 167/Glenn County.

Figure D13. DAU 168/Butte County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



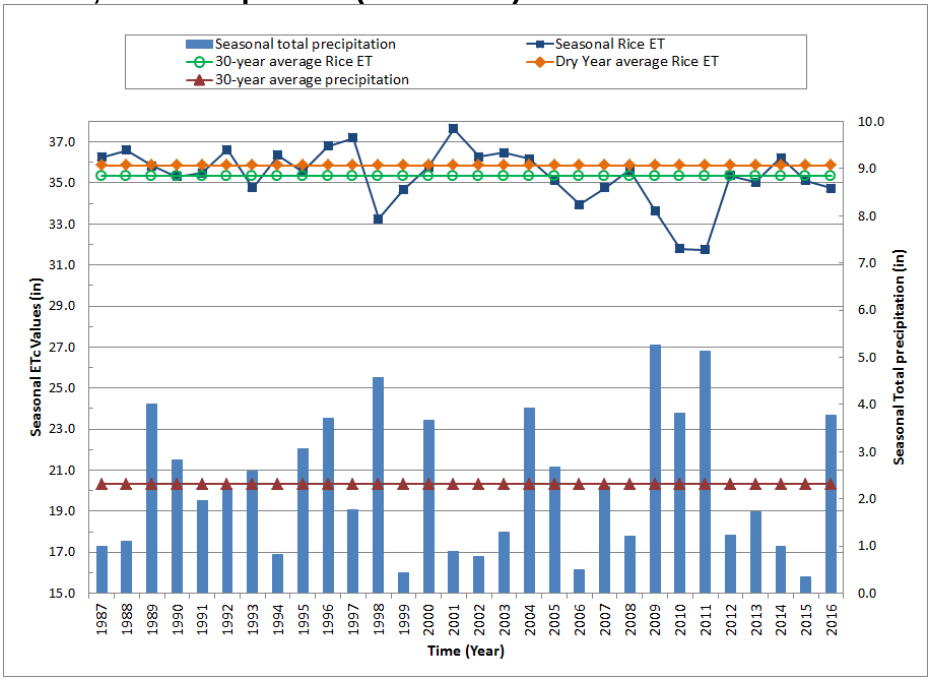
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in Detailed Analysis Unit (DAU) 168/Butte County.

Figure D14. DAU 168/Sutter County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



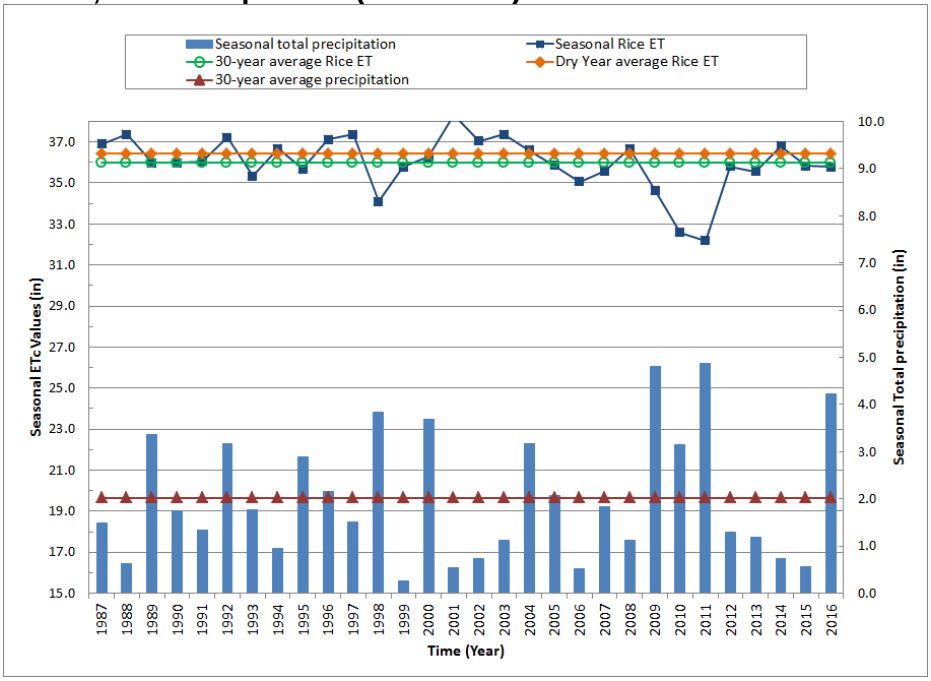
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 168/Sutter County.

Figure D15. DAU 171/Yuba County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



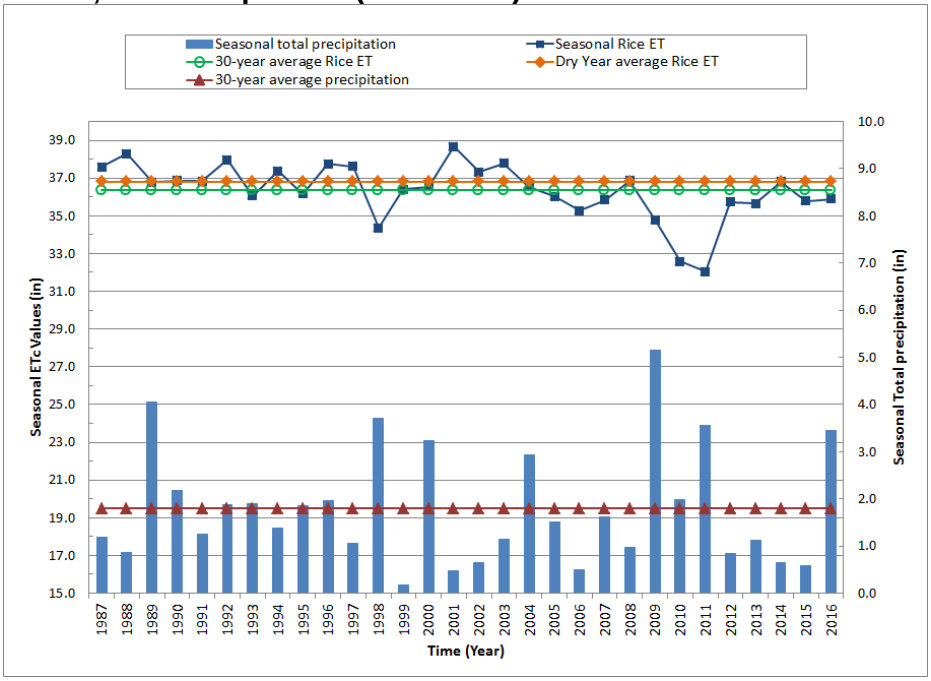
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 171/Yuba County.

Figure D16. DAU 172/Placer County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



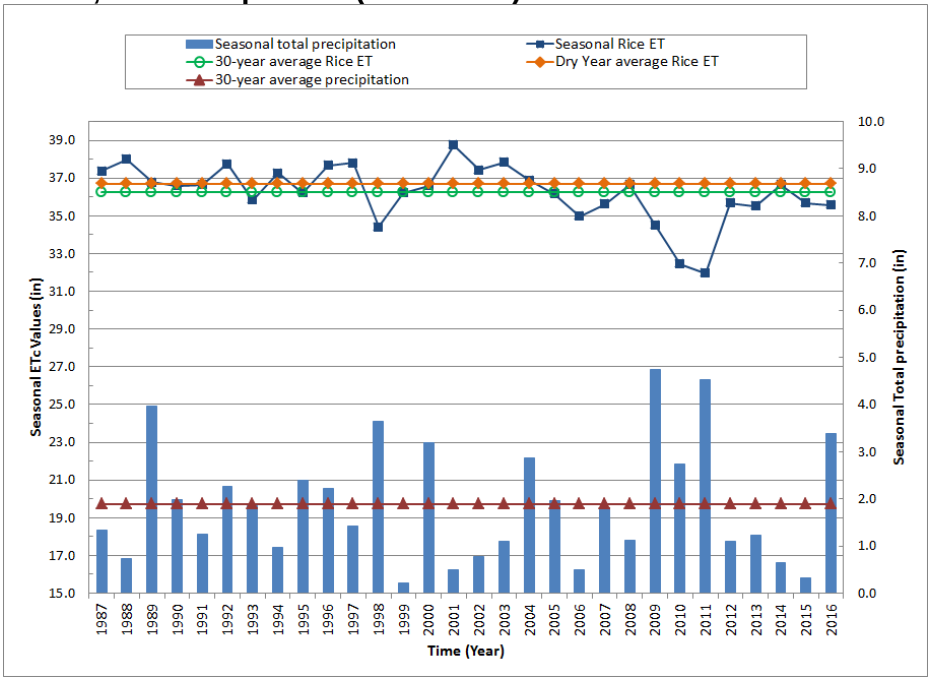
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 172/Placer County.

Figure D17. DAU 172/Sacramento County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



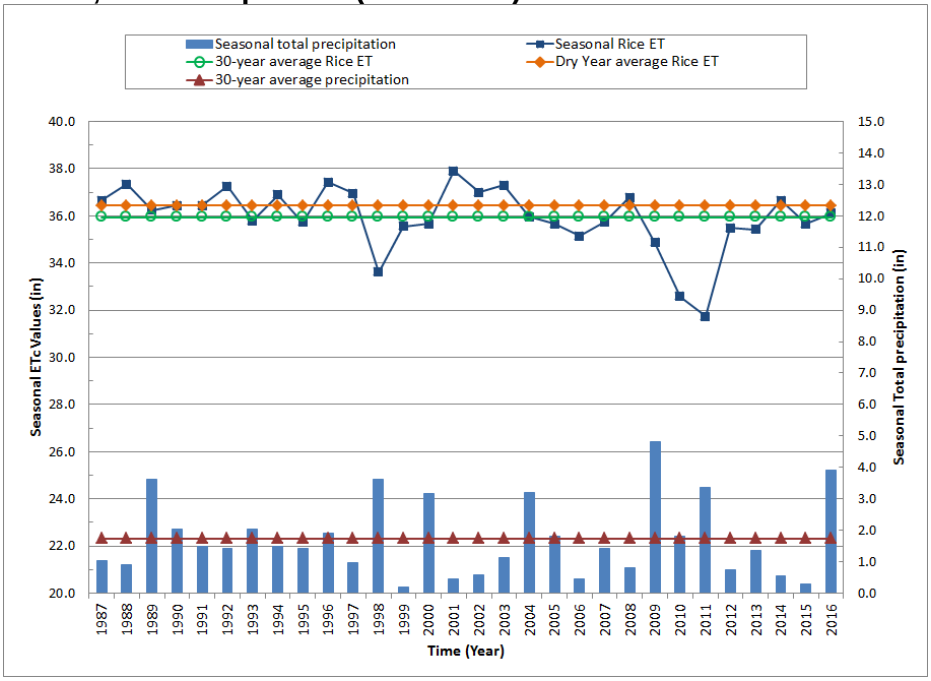
Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 172/Sacramento County.

Figure D18. DAU 172/Sutter County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 172/Sutter County.

Figure D19. DAU 186/Yolo County Seasonal Estimates and 30-Year Averages of ETc, and Precipitation (1987–2016)



Notes: DAU = detailed analysis unit, ET = evapotranspiration, ETc = crop evapotranspiration
Figure includes average seasonal soil evaporation during dry years, and average seasonal measurements of ETc for dry rice during 2012–2013 in DAU 186/Yolo County.

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STATE OF CALIFORNIA